

Anesthesia and Peri-Operative Medicine

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Anesthesia Basics

6 A's of General Anesthesia

1. Anesthesia
2. Anxiolysis
3. Amnesia
4. Areflexia (muscle relaxation not always required)
5. Autonomic Stability
6. Analgesia

Types of Anesthesia

- **general**
 - general anesthesia
 - total IV anesthesia (TIVA)
- **regional**
 - spinal, epidural
 - peripheral nerve block
 - IV regional
- **local**
 - local infiltration
 - topical
- **sedation**
 - monitored anesthesia care
- note that different types of anesthesia can be combined (e.g. general + regional)

Pre-Operative Assessment

- to identify the patient's medical and surgical issues; to allow for the arrangement of further investigations, consultations and treatments for patients not yet optimized; and to plan anesthetic techniques

History and Physical

History

- indication for surgery
- surgical/anesthetic Hx: previous anesthetics/complications, previous intubations, medications, drug allergies
- PMHx
 - CNS: seizures, stroke, raised intracranial pressure (ICP), spinal disease
 - CVS: coronary artery disease (CAD), myocardial infarction (MI), congestive heart failure (CHF), hypertension (HTN), valvular disease, dysrhythmias, peripheral vascular disease (PVD), conditions requiring endocarditis prophylaxis, exercise tolerance, CCS class, NYHA class (see Cardiology and Cardiovascular Surgery, C33 for NYHA classification)
 - respiratory: smoking, asthma, chronic obstructive pulmonary disease (COPD), recent upper respiratory tract infection (URTI), sleep apnea
 - GI: gastroesophageal reflux disease (GERD), liver disease
 - renal: insufficiency, dialysis, CKD
 - hematologic: anemia, coagulopathies, blood dyscrasias
 - MSK: conditions associated with difficult intubations – arthritides (e.g. rheumatoid arthritis), cervical tumours, cervical infections/abscess, trauma to cervical spine, Down syndrome, scleroderma, obesity, conditions affecting neuromuscular junction (e.g. myasthenia gravis)
 - endocrine: diabetes, thyroid, adrenal disorders
 - other: morbid obesity, pregnancy, ethanol/other drug use
- FHx: malignant hyperthermia, atypical cholinesterase (pseudocholinesterase), other abnormal drug/anesthetic reactions

Physical Examination

- oropharynx and airway assessment to determine the likelihood of difficult intubation
- ability to assume “sniffing position” – upper cervical spine extension, lower cervical spine flexion (assesses likelihood of difficult intubation)
- no single test is specific or sensitive – all aid in determining the ease of intubation
 - Mallampati Classification (Figure 1)
 - thyromental distance (the distance of the lower mandible in the midline from the mentum to the thyroid notch)
 - ♦ with the adult patient's neck fully extended, <3 finger breadths (<6 cm) is associated with difficult intubation

- mouth opening (<2 finger breadths is associated with difficult intubation)
- tongue size
- dentition, dental appliances/prosthetic caps – must inform patients of the rare possibility of damage
- nasal passage patency (if planning nasotracheal intubation)
- bony landmarks and suitability of anatomy for regional anesthesia (if relevant)
- focused physical exam of the CNS, CVS, and respiratory systems
- general assessment of nutrition, hydration, and mental status
- pre-existing motor and sensory deficits
- sites for IV, central venous pressure (CVP), and pulmonary artery (PA) catheters

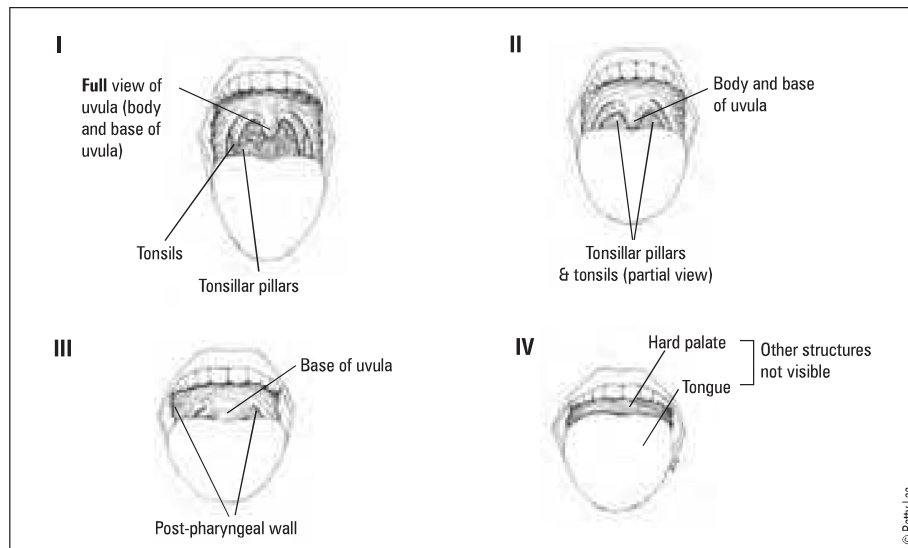


Figure 1. Mallampati Classification of Upper Airway Visualization

Pre-Operative Investigations

Table 1. Suggested Indications for Specific Investigations in the Pre-Operative Period

Test	Indications
CBC	Major surgery requiring group and screen or cross and match; chronic cardiovascular, pulmonary, renal, or hepatic disease; malignancy; known or suspected anemia; bleeding diathesis or myelosuppression in patient less than 1 year of age
Sickle cell screen	Genetically predisposed patient (hemoglobin electrophoresis if screen is positive)
INR, aPTT	Anticoagulant therapy, bleeding diathesis, liver disease
Electrolytes and Creatinine	Hypertension, renal disease, diabetes, pituitary or adrenal disease; digoxin or diuretic therapy, or other drug therapies affecting electrolytes; age >50
Fasting glucose level	Diabetes (repeat on day of surgery)
Pregnancy (beta-HCG)	Women of childbearing age
ECG	Heart disease, hypertension, diabetes, other cardiac risk factors (may include age), subarachnoid hemorrhage, CVA, head trauma, age (male >40 y.o., female >50 y.o.)
Echocardiogram	CHF, cardiomyopathy, valvular pathology, limited cardiac reserve, stroke of unknown etiology
Chest radiograph	Cardiac or pulmonary disease, malignancy, age >60

Guidelines to the Practice of Anesthesia, Revised 2006. Supplement to the Canadian Journal of Anesthesia, Vol 53(12), Dec. 2006. Reproduced with permission © Canadian Anesthesiologists' Society.

Fasting Guidelines

Fasting Guidelines Prior to Surgery (Canadian Anesthesiologists' Society)

- **8 hours** after a meal that includes meat, fried or fatty foods
- **6 hours** after a light meal (such as toast, crackers and clear fluid) or after ingestion of infant formula or nonhuman milk
- **4 hours** after ingestion of breast milk or jello
- **2 hours** after clear fluids (water, black coffee, tea, carbonated beverages, juice without pulp)

Impact of Anesthesia Management Characteristics on Severe Morbidity and Mortality

Anesthesiology 2005; 102(2):257-258

Study: Case-control study of patients undergoing anesthesia.

Patients: 803 cases and 883 controls were analyzed among a cohort of 869,483 patients undergoing anesthesia between 1995-1997. Cases were defined as patients who either remained comatose or died within 24 hours of receiving anesthesia. Controls were defined as patients who neither remained comatose nor died within 24 hours of receiving anesthesia.

Intervention: General, regional, or combined anesthesia to patients undergoing a surgical procedure.

Main Outcome: coma or death within 24 hours of receiving anesthesia

Results: The incidence of 24-hour postoperative death was 8.8 per 10,000 anesthetics (95% CI, 8.2–9.5) and the incidence of coma was 0.5 (95% CI, 0.3–0.6). Anesthesia management risk factors that were associated with a decreased risk of morbidity and mortality were: equipment check with protocol and documentation, directly available anesthesiologist with no change during anesthesia, 2 persons present at emergence of anesthesia, reversal of muscle relaxation, and postoperative pain medication.

American Society of Anesthesiology (ASA) Classification

- common classification of physical status at the time of surgery
- a gross predictor of overall outcome, NOT used as stratification for anesthetic risk (mortality rates)
- **ASA 1:** a healthy, fit patient
- **ASA 2:** a patient with mild systemic disease, e.g. controlled Type 2 diabetes, controlled essential HTN, obesity, smoker
- **ASA 3:** a patient with severe systemic disease that limits activity, e.g. stable CAD, COPD, DM, obesity
- **ASA 4:** a patient with incapacitating disease that is a constant threat to life, e.g. unstable CAD, renal failure, acute respiratory failure
- **ASA 5:** a moribund patient not expected to survive 24 hours without surgery, e.g. ruptured abdominal aortic aneurysm (AAA), head trauma with increased ICP
- for emergency operations, add the letter E after classification (e.g. ASA 3E)

Pre-Operative Optimization

- in general, any fluid and/or electrolyte imbalance should be corrected prior to elective surgery

Medications

- pay particular attention to cardiac and respiratory meds, narcotics and drugs with many side effects and interactions
- **pre-operative medications to start**
- prophylaxis
 - risk of GE reflux: sodium citrate 30 mL PO or ranitidine 150-300 mg PO 30 min to 1 hour pre-op
 - risk of infective endocarditis, GI/GU interventions: antibiotics
 - risk of adrenal suppression: steroid coverage
 - risk of DVT: heparin SC
 - consider oral benzodiazepines for the anxious patient
- optimization of co-existing disease: bronchodilators (COPD, asthma), nitroglycerin and beta-blockers (CAD risk factors)
- **pre-operative medications to stop**
 - oral hypoglycemics: stop on morning of surgery
 - antidepressants (tricyclics, MAOIs): stop on morning of surgery
- **pre-operative medication to adjust**
 - insulin, prednisone, coumadin, bronchodilators

Hypertension

- mild to moderate HTN is not an independent risk factor for peri-operative cardiovascular complications (*Lette et al. Ann. Surg.* 1992; 216:192-204)
- target sBP <180 mmHg, dBP <110 mmHg
- assess for absence/presence of end-organ damage and treat accordingly

Coronary Artery Disease (CAD)

- ACC/AHA Guidelines (2007) recommend postponing elective surgery 4-6 weeks following an MI
- this period carries an increased risk of reinfarction/death
 - <3 months after MI – 37% patients may reinfarct
 - 3-6 months after MI – 15%
 - >6 months after MI – risk remains constant at 5%
- if operative procedure is essential, and cannot be delayed, invasive intra and post-operative ICU monitoring reduces the risk to 6%, 2% and 1% respectively for the above time periods
- mortality with peri-operative MI is 20-50%
- initiation of peri-operative beta-blockade in patients with increased risk of CVA
 - beta-blockade should be continued if already started
 - initiate beta-blockade if inducible ischemia, CAD or multiple cardiac risk factors and undergoing high risk surgery
 - consider initiating beta-blockade if CAD or multiple cardiac risk factors and undergoing intermediate risk surgery
 - treatment with beta-blockers should be optimized well in advance of any surgery



Risk Assessment

1. Reconcile patient factors with surgical needs and devise a safe and effective anesthetic plan
2. Optimize co-morbidities

Effects of Extended-release Metoprolol Succinate in Patients Undergoing Non-Cardiac Surgery (POISE trial): A Randomised Controlled Trial.

Lancet 2008; 371:1839-47

Purpose: To investigate the role of beta-blockers (metoprolol) peri-operatively in patients with known vascular disease, undergoing non-cardiac surgery.

Methods: Patients from 190 centres in 23 countries were eligible if they were >45, undergoing non-cardiac surgery and were known to have significant vascular disease. Patients were randomised to either the metoprolol group or placebo. Participants received metoprolol (or placebo) 100 mg 2-4 hours before surgery and again 6 hours after surgery and following that 200 mg daily for 30 days. The primary endpoint was a composite of cardiovascular death, non-fatal myocardial infarction and non-fatal cardiac arrest. Analyses was by intention to treat.

Results: 8351 patients were recruited into the study, with 8331 completing the 30 day course. Use of metoprolol was found to significantly reduce the risk of cardiovascular death, non-fatal MI or non-fatal cardiac arrest vs. placebo (hazard ratio 0.84, $p < 0.05$) but significantly increased the rate of stroke (hazard ratio 2.17, $p < 0.01$) and overall risk of death (hazard ratio 1.33, $P < 0.05$).

Conclusion: Use of peri-operative beta-blockers (metoprolol) in patients with known vascular disease provides both risks and benefits, and these must be considered for each patient individually.

Endocrine Disorders

- diabetes mellitus
 - hypoglycemia
 - ♦ caused by drugs and surgical stresses and masked by anesthesia
 - ♦ prevent with dextrose/insulin infusion and blood glucose monitoring
 - end organ damage: be aware of damage to CVS, renal and nervous systems, including autonomic neuropathy
- hyperthyroidism
 - can experience sudden release of thyroid hormone (thyroid storm)
 - treatment: beta-blockers + pre-op prophylaxis
- adrenocortical insufficiency e.g. Addison's, exogenous steroid use
 - steroid coverage suggested if steroid use of >1 week in past 6 months

Respiratory Diseases

- asthma
 - bronchospasm from intubation, delivery of inhaled anesthetics
 - pre-op inhaled salbutamol may mitigate risk
 - avoid non-selective beta-blockers, caution with beta2 specific
 - cancel/delay elective surgery for poorly controlled asthma
- smoking
 - adverse effects: altered mucus secretion and clearance, decreased small airway caliber and altered immune response
 - abstain at least 8 weeks pre-op, if possible
 - if unable, abstaining even 24 hours pre-op has shown benefit
- COPD
 - anesthesia, surgery and analgesia predispose to atelectasis, bronchospasm, pneumonia, prolonged mechanical ventilation and respiratory failure
 - cancel/delay elective surgery for acute exacerbation
 - optimize with bronchodilators ± inhaled corticosteroids ± antibiotics

Aspiration

- risk of aspiration in gastroesophageal (GE) sphincter incompetency, GERD or hiatus hernia
- avoid inhibiting airway reflexes; reduce gastric volume and acidity
- employ rapid sequence induction if increased risk (see *RSI*, A9)
- increased risk with laryngeal mask (instead of ETT)

Monitoring

Canadian Guidelines to the Practice of Anesthesia and Patient Monitoring

- an anesthetist present: "the only indispensable monitor"
- a completed pre-anesthetic checklist: including ASA class, NPO policy, Hx and investigations
- a peri-operative anesthetic record: HR and BP q5min, dose and route of drugs and fluids
- continuous monitoring:
 - oxygenation
 - ventilation
 - circulation
 - temperature

Routine Monitors for All Cases

- **BP cuff, telemetry, pulse oximeter** (O₂ saturation), stethoscope, temperature probe, gas analyzer, capnometer (end tidal CO₂ to assess adequacy of ventilation)

Elements to Monitor (Figure 2)

- anesthetic depth
 - inadequate: blink reflex present when eyelashes lightly touched, HTN, tachycardia, tearing or sweating
 - excessive: hypotension, bradycardia
- oxygenation: pulse oximetry, inspired O₂ concentration (FiO₂)
- ventilation: verification of correctly positioned ETT, chest excursions, breath sounds, end tidal CO₂ analysis, end tidal inhaled anesthesia analysis
- circulation: pulse, heart sounds, BP, telemetry, oximetry, central venous pressure (CVP), pulmonary capillary wedge pressure
- temperature: temperature probe



Pre-Anesthetic Checklist

SAMMM

Suction – connected and working
Airways – laryngoscope and blades, ETT, syringe, stylet, oral and nasal airways, tape, bag and mask
Machine – connected, pressures okay, all meters functioning, vaporizers full
Monitors – available, connected and working
Medications – IV fluids and kit ready, emergency medicines in correct location and accessible

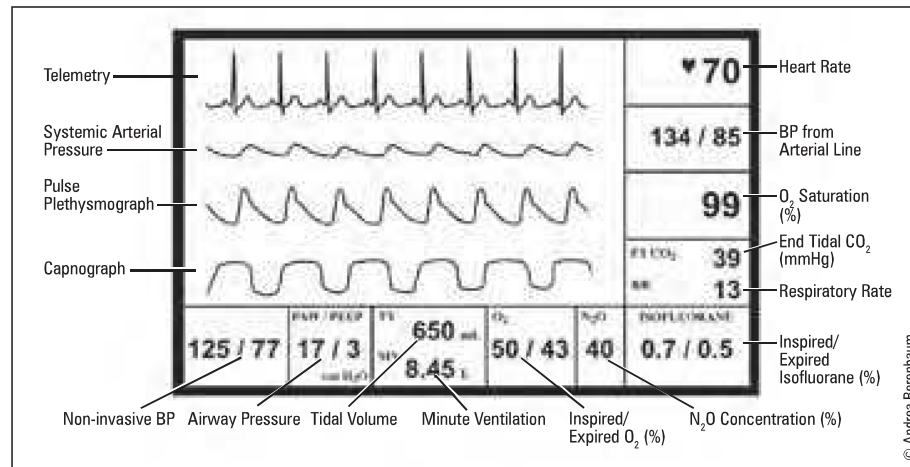


Figure 2. Typical Anesthesia Monitor

Induction Agents

- induction may be achieved with intravenous agents, volatile agents or both

Intravenous Agents

- Table 11, A25
- the IV induction agents include a selection of non-opioid drugs used to provide amnesia and blunt reflexes. These are initially used to draw the patient into the maintenance phase of general anesthesia rapidly, smoothly, and with little adverse effects
 - e.g. propofol, sodium thiopental or ketamine
 - propofol and ketamine are also used for the maintenance phase of GA

Volatile Inhalational Agents

- Table 13, A26
- general concepts of volatile agents are discussed below
 - e.g. sevoflurane, desflurane, isoflurane, enflurane, halothane and nitrous oxide

MAC (minimum alveolar concentration)

- definition: the alveolar concentration of an agent at one atmosphere (atm) of pressure that will prevent movement in 50% of patients in response to a surgical stimulus (e.g. abdominal incision)
- often 1.2-1.3 times MAC will ablate response in the general population
- potency of inhalational agents is compared using MAC
- MAC values are roughly additive when mixing N₂O with another volatile agent (i.e. 0.5 MAC of a potent agent + 0.5 MAC of N₂O = 1 MAC of potent agent; however, this only applies to movement, not other effects such as blood pressure changes and does not hold over the entire N₂O dose range)
- MAC-intubation: the MAC of anesthetic that will inhibit movement and coughing during endotracheal intubation, generally 1.3 MAC
- MAC-block adrenergic response (MAC-BAR): the MAC necessary to blunt the sympathetic response to noxious stimuli, generally 1.5 MAC
- MAC-awake: the MAC of a given volatile anesthetic at which a patient will open their eyes to command, usually 0.3-0.4 of the usual MAC value



Determinants of Speed of Onset of Volatile Anesthetics

- Solubility:** decrease solubility, increase rate of induction
- Cardiac Output (CO):** as CO increases, anesthetic uptake to blood increases and alveolar gas concentration decreases, thus delaying induction
- Partial pressure difference between alveolar and venous blood:** increase gradient, decrease rate of induction
- Inspired Gas Concentration:** increase inspired concentration, increase rate of induction
- Alveolar Ventilation:** increase alveolar ventilation, increase rate of induction
- Second Gas Effect:** when 2 gases are administered together, uptake of the first gas (e.g. N₂O) increases the alveolar concentration of the second gas (e.g. desflurane), increase rate of induction



Solubility of Volatile Anesthetics in Blood Least soluble → Most soluble

Nitrous oxide < desflurane < sevoflurane < isoflurane < halothane

Muscle Relaxants and Reversing Agents

- depolarizing muscle relaxants: succinylcholine (SCh)
- non-depolarizing: rocuronium, mivacurium, vecuronium
- specific muscle relaxants are described in Tables 14 and 15

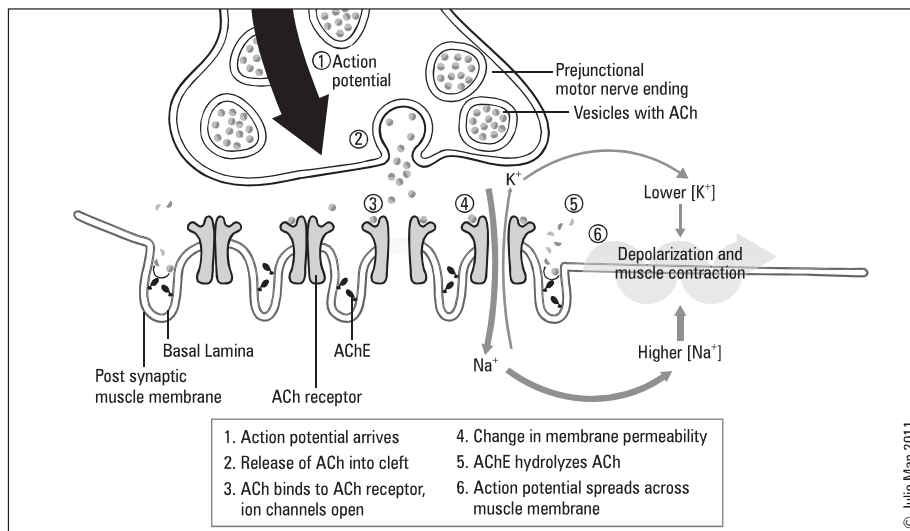


Figure 3. Anatomy and Physiology of the Neuromuscular Junction (NMJ)

Muscle Relaxants

- muscle relaxation produces the following desired effects:
 1. facilitates intubation
 2. assists with mechanical ventilation
 3. prevents muscle stretch reflex and decreases muscle tone
 4. allows access to the surgical field (intracavitary surgery)
- never use without adequate preparation and equipment to maintain airway and ventilation
- blocks nicotinic cholinergic receptors in NMJ
- provides skeletal muscle paralysis, including the diaphragm, but spares involuntary muscles such as the heart and smooth muscle
- nerve stimulator is used intraoperatively to assess the degree of nerve block; no twitch response seen with complete neuromuscular blockade

Reversing Agents for Non-Depolarizing Muscle Relaxants (e.g. neostigmine, pyridostigmine, edrophonium)

- reversal agents are acetylcholinesterase inhibitors
 - inhibits enzymatic degradation of ACh; increases amount of ACh at nicotinic and muscarinic receptors, displacing non-depolarizing muscle relaxant
- anticholinergic agents, such as atropine or glycopyrrolate, are simultaneously administered to minimize muscarinic effect of reversal agents (i.e. bradycardia, salivation and increased bowel peristalsis)



Plasma Cholinesterase

Plasma cholinesterase is produced by the liver and metabolizes SCh, ester local anesthetics, and mivacurium. A prolonged duration of blockade by SCh occurs with:

- (a) decreased quantity of plasma cholinesterase, e.g. liver disease, pregnancy, malignancy, malnutrition, collagen vascular disease, hypothyroidism.
- (b) abnormal quality of plasma cholinesterase, i.e. normal levels but impaired activity of enzymes, genetically inherited.

Airway Management

Airway Anatomy Review

- normal airway: nares → nasal cavities → nasal pharynx → laryngeal pharynx → trachea
- resistance to airflow through nasal passages accounts for approximately 2/3 of total airway resistance
- pharyngeal airway extends from posterior aspect of the nose to cricoid cartilage
- the glottic opening (triangular space formed between the true vocal cords) is the narrowest segment of the laryngeal opening in adults
- when intubating, the glottic opening is used as the space through which one visualizes proper placement of the endotracheal tube (ETT)
- the trachea begins at the level of the thyroid cartilage at the level of C6
- the trachea bifurcates into the right and left main bronchi at the level of T5

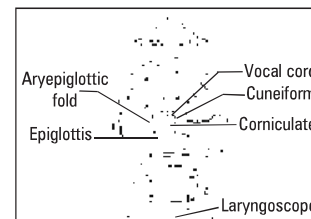


Figure 4. Landmarks for Intubation

Table 2. Methods of Supporting the Airway

	Bag and Mask	Laryngeal Mask Airway (LMA)	Endotracheal Tube (ETT)
Advantages/Indications	• Basic • Non-invasive • Readily available	• Easy to insert • Less airway trauma/irritation than ETT • Frees up hands (vs. face mask) • Primarily used in spontaneously ventilating patient	• "The 5 P's" • Ensures airway Patency • Protects against aspiration • Allows Positive pressure ventilation • Allows suctioning i.e. "Pulmonary toilet" • A route for Pharmacological administration
Disadvantages/Contraindications	• Risk of aspiration if ↓ LOC • Cannot ensure airway patency • Inability to deliver precise tidal volume • Operator fatigue	• Risk of gastric aspiration • PPV > 20 cm H₂O needed • Limited TMJ mobility • C-spine or laryngeal cartilage fracture • Oropharyngeal, retropharyngeal pathology or foreign body	• Insertion can be difficult • Muscle relaxant usually needed • Laryngospasm may occur on failed intubation or extubation • Sympathetic stress due to intubation
Other	• Facilitate airway patency with jaw thrust and chin lift • Can use oropharyngeal/nasopharyngeal airway	• Does NOT protect against laryngospasm or gastric aspiration • Sizing (approx): 40-50 kg: 3 50-70 kg: 4 70-100 kg: 5	• Auscultate to avoid endobronchial intubation • Sizing (approx): Male: 8.0-9.0 mm Female: 7.0-8.0 mm Pediatric: (age/4) + 4 mm



Tracheal Intubation

Equipment for Intubation

- oxygen source and self-inflating bag
- face mask (appropriate size and one size larger and smaller)
- oropharyngeal and nasopharyngeal airways
- endotracheal tubes (appropriate size and one size smaller)
- tracheal stylet
- syringe for tube cuff inflation
- suction
- laryngoscopes

Preparing for Intubation

- failed attempts at intubation can make further attempts more difficult due to tissue trauma
- plan, prepare and assess for potential difficulties (see *Pre-operative Assessment, A2*)
- ensure equipment is available and working (e.g. test ETT cuff, check laryngoscope light, machine check)
- pre-oxygenate/denitrogenate: patient breathes 100% O₂ for 3-5 min or for 4 vital capacity breaths
- may need to suction mouth and pharynx first

Proper Positioning for Intubation

- "sniffing position": flexion of lower C-spine (C5,6), i.e. bow head forward and extension of upper C-spine at atlanto (C1)-occipital joint, i.e. nose in the air
- aligns the three axes of mouth, pharynx and larynx to allow visualization from the oral cavity to the glottis (Figure 5)
- proper position for laryngoscope tip to visualize cords is in the epiglottic vallecula
- contraindicated in known/suspected C-spine fracture/instability

Tube Insertion

- ETT insertion can incite a significant sympathetic response due to a "foreign body reflex" in the trachea, including: tachycardia, dysrhythmias, myocardial ischemia, increased BP and coughing
- a malpositioned ETT is a potential hazard for the intubated patient
 - if too deep, may result in right endobronchial intubation, which is associated with left-sided atelectasis and right-sided tension pneumothorax
 - if too shallow, may lead to accidental extubation, vocal cord trauma or laryngeal paralysis as a result of pressure injury by the ETT cuff
- the tip of ETT should be located at the midpoint of the trachea at least 2 cm above the carina and the proximal end of the cuff should be placed at least 2 cm below the vocal cords
 - approximately 20-23 cm mark at the right corner of the mouth for men and 19-21 cm for women

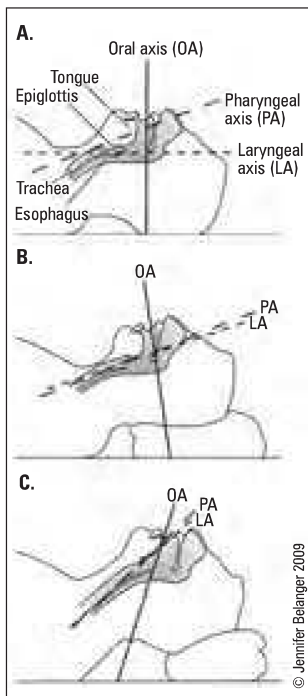


Figure 5. Anatomic Considerations in Laryngoscopy

A. neutral position, B. C-spine flexion, C. C-spine flexion with atlanto-occipital extension.

Confirmation of Tracheal Placement of ETT

- direct
 - visualization of ETT passing through cords
 - bronchoscopic visualization of ETT in trachea
- indirect
 - end-tidal CO₂ in exhaled gas measured by capnograph
 - auscultate for equal breath sounds bilaterally and absent breath sounds over epigastrium
 - chest movement and no abdominal distention
 - feel the normal compliance of lungs when ventilating patient
 - condensation of water vapour in ETT visible during exhalation
 - refilling of reservoir bag during exhalation
 - AP or lateral CXR: ETT tip at midpoint of thoracic inlet and carina (lateral CXR more sensitive and specific)

Complications During Laryngoscopy and Intubation

- mechanical
 - dental damage
 - laceration (lips, gums, tongue, pharynx, esophagus)
 - laryngeal trauma
 - esophageal or endobronchial intubation
 - accidental extubation
 - insufficient cuff inflation or cuff laceration: results in leaking and aspiration
- systemic
 - laryngospasm
 - bronchospasm
- esophageal intubation suspected when
 - end-tidal CO₂ zero or near zero on capnograph
 - abnormal sounds during assisted ventilation
 - impairment of chest excursion
 - hypoxia/cyanosis
 - presence of gastric contents in ETT
 - distention of stomach/epigastrium with ventilation



Intubation Tools

MD SOLES

Monitoring
Drugs
Suction
Oxygen
Laryngoscopes
ETT
Stylet, Syringe



Medications that can be given through the ETT

NAVEL

Naloxone
Atropine
Ventolin
Epinephrine
Lidocaine



Differential Diagnosis of Poor Bilateral Breath Sounds after Intubation

DOPE

Displaced ETT
Obstruction
Pneumothorax
Esophageal intubation

Rapid Sequence Induction (RSI)

- indicated when patient has “full stomach”, i.e. predisposed to regurgitation/aspiration:
 - decrease level of consciousness (LOC)
 - trauma
 - meal within 6 hours
 - sphincter incompetence suspected (GERD, hiatus hernia, nasogastric tube)
 - increased abdominal pressure (pregnancy, obesity, bowel obstruction, acute abdomen)
- pre-oxygenate/denitrogenate: patient breathes 100% O₂ for 3-5 minutes or for 4 vital capacity breaths prior to induction of anesthesia (do NOT bag ventilate)
- assistant performs Sellick's maneuver: pressure on cricoid cartilage to compress esophagus between cartilage and C6 to prevent reflux/aspiration
- administration of induction agent immediately followed by fast acting muscle relaxant (e.g. SCH)
- intubate shortly after administration of muscle relaxant (approximately 45-60 seconds) with no bag-mask ventilation in between induction and intubation
- must use cuffed ETT to prevent aspiration of gastric contents
- inflate cuff, verify correct placement of ETT, release cricoid cartilage pressure
- ventilate when ETT in place and cuff inflated

Difficult Airway

- difficulties with bag-mask ventilation, supraglottic airway, endotracheal intubation, infraglottic airway or surgical airway
- algorithms exist for difficult airways (e.g. *Anesthesiology* 2003; 98:3273, *Anaesthesia* 2004; 59:675)
- pre-op assessment (history of previous difficult airway, airway examination) and pre-oxygenation are important preventative measures
- if difficult airway expected, consider:
 - awake intubation
 - intubating with bronchoscope, trachlight (lighted stylet), fibre-optic laryngoscope, glidescope, etc.
- if intubation unsuccessful after induction:
 1. CALL FOR HELP
 2. ventilate with 100% O₂ via bag and mask
 3. consider returning to spontaneous ventilation and/or waking patient

Predicting Difficult Intubation in Apparently Normal Patients

Anesthesiology 2005; 103:429-37

Purpose: To assess widely available bedside tests and widely used laryngoscopic techniques in the prediction of difficult intubations.

Study: Meta-analysis.

Patients: 35 studies encompassing 50,760 patients.

Definitions: Difficult intubation was defined usually as Cormack-Lehane grade of 3 or greater, but some authors reported the requirement of a special technique, multiple unsuccessful attempts, or a combination of these as the accepted standard for difficult intubation.

Results: The overall incidence of difficult intubation was 5.8% (95% CI, 4.5–7.5%) for the overall patient population, 6.2% (95% CI, 4.6–8.3%) for normal patients excluding obstetric and obese patients, 3.1% (95% CI, 1.7–5.5%) for obstetric patients, and 15.8% (95% CI, 14.3–17.5%) for obese patients.

Mallampati score: SN: 49% SP:86% PLR:3.7 NLR:0.5, Thyromental distance: SN:20% SP:94% PLR:3.4 NLR:0.8 Sternomental distance: SN:62% SP:82% PLR:5.7 NLR:0.5, Mouth opening: SN:22% SP:97% PLR: 4.0 NLR:0.8, Wilson risk-sum: SN:46% SP:89% PLR:5.8 NLR:0.6, Combination Mallampati and thyromental distance: SN:36% SP:87% PLR:9.9 NLR:0.6

Conclusions: A combination of the Mallampati test and thyromental distance is the most accurate at predicting difficult intubation. The positive likelihood ratio (9.9) is supportive of the test as a good predictor of difficult intubation.

PLR: Positive likelihood ratio; NLR: Negative likelihood ratio; SN: Sensitivity; SP: Specificity

- if bag and mask ventilation inadequate:
 1. CALL FOR HELP
 2. attempt ventilation with oral airway
 3. consider/attempt LMA
 4. emergency invasive airway access (e.g. rigid bronchoscope, cricothyrotomy or tracheostomy)

Intraoperative Management

Oxygen Therapy

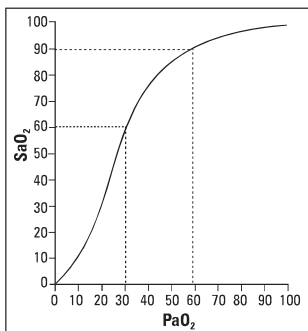


Figure 6. HbO₂ Saturation Curve



Alveolar O₂ Gas Equation

$$PAO_2 = FiO_2 (P_{atm} - P_{H_2O}) - PaCO_2$$



Arterial O₂ Content

$$CaO_2 = (SaO_2)(Hb)(1.34) + (PaO_2)(0.003)$$

CaO₂ = arterial O₂ content

SaO₂ = % hemoglobin saturation

PaO₂ = arterial O₂ pressure

- in general the goal of oxygen therapy is to maintain oxygen saturation (SaO₂) >90%
- below an SaO₂ of 90%, a small decrease in saturation corresponds to a large drop in PaO₂ (Figure 6)
- in intubated patients, oxygen is delivered via the endotracheal tube (ETT)
- in patients not intubated, there are many oxygen delivery systems available; the choice depends on oxygen requirements (FiO₂) and the degree to which precise control of delivery is needed
- cyanosis can be detected at SaO₂ = 80%, frank cyanosis at SaO₂ = 67%

Low Flow Systems

- acceptable if tidal volume 300-700 ml, respiratory rate (RR) <25, consistent ventilation pattern
- provide O₂ at flows between 0-8 L/min
- dilution of oxygen with room air results in a decrease in the inspired oxygen concentration (FiO₂)
- an increase in minute ventilation (tidal volume x RR) results in a decrease in the inspired oxygen concentration
- e.g. **nasal cannula (prong)**
 - well tolerated if flow rates <5-6 L/min, at high flows drying of nasal mucosa
 - the nasopharynx acts as an anatomic reservoir that collects O₂
 - the delivered oxygen concentration (FiO₂) can be estimated by adding 4% for every additional litre of O₂ delivered (e.g. at normal tidal volume and RR, flow rate of 1-6 L/min equate to FiO₂ of 24-44%)

Reservoir Systems

- use a volume reservoir to accumulate oxygen during exhalation thus increasing the amount of oxygen available for the next breath
- **simple face mask (Hudson face mask)**
 - covers patient's nose and mouth and provides an additional reservoir beyond nasopharynx
 - fed by small bore O₂ tubing at a rate of at least 6 L/min to ensure that exhaled CO₂ is flushed through the exhalation ports and not rebreathed
 - FiO₂ of 55% can be achieved at O₂ flow rates of 10 L/min
- **non-rebreather mask**
 - reservoir bag and a series of one-way valves direct gas flow from the bag on inhalation and allow release of expired gases on exhalation, thus allowing for oxygen accumulation during intubation
 - O₂ flow rates of 10-15 L/min are needed to maintain the reservoir bag inflation and should deliver FiO₂ >80%

High Flow Systems

- generates flows of up to 50-60 L/min
- meets/exceeds patient's inspiratory flow requirement
- delivers consistent and predictable concentration of O₂
- **Venturi mask**
 - delivers specific percentages of oxygen by varying the size of air entrainment
 - port determines the oxygen concentration (i.e. can vary to achieve 24%, 28%, 35%, 50%)
 - enables control of gas humidity
- **Puritan mask**
 - delivers the highest level of humidified oxygen

Ventilation

- in patients given muscle relaxants, ventilation is maintained with positive pressure ventilation (PPV)
- if no muscle relaxant is given patients may have sufficient spontaneous respirations to maintain ventilation, or assisted/controlled ventilation can be used

- other indications of mechanical ventilation:
 - apnea
 - hypoventilation
 - intraoperative positioning limiting respiratory excursion (e.g. prone, Trendelenburg)
 - required hyperventilation (to lower intracranial pressure)
 - deliver positive end expiratory pressure (PEEP)
 - increased intrathoracic pressure (e.g. laparoscopic procedure)
- complications of mechanical ventilation:
 - decreased CO₂ due to hyperventilation
 - decreased BP due to decreased venous return from increased intrathoracic pressure
 - alkalemia with over correction of chronic hypercarbia
 - nosocomial pneumonia/bronchitis
- see Respirology, R27 for ventilatory modes

Table 3. Causes of Intraoperative Hyper- and Hypocapnea

Hypocapnea (↓ CO ₂)	Hypercapnea (↑ CO ₂)
Hyperventilation	Hypoventilation
Hypothermia	Hyperthermia
Decreased blood flow to lungs	Improved blood flow to lungs after resuscitation or hypotension
Incorrect placement of sampling catheter	Low bicarbonate
Inadequate sampling volume	Anesthetic breathing circuit error • Inadequate fresh gas flow • Rebreathing, faulty circuit absorber valves • Exhausted soda lime
Incipient pulmonary edema	
Air embolism	Water in capnography device

Temperature

Causes of Hypothermia (<36.0°C)

- intraoperative temperature losses are common (e.g. 90% of intraoperative heat loss is transcutaneous), due to:
 - OR environment (cold room, IV fluids, instruments)
 - open wound
- prevent with inflated warming blanket and warmed IV fluids (if giving platelet transfusion put through a line that does not go through warmer, warmer distorts viability of platelets)

Causes of Hyperthermia (>37.5-38.3°C)

- drugs (e.g. atropine)
- blood transfusion reaction
- infection/sepsis
- medical disorder (e.g. thyrotoxicosis)
- malignant hyperthermia (see *Uncommon Complications*, A24)
- over-zealous warming efforts

Heart Rate

Causes of Intraoperative Tachycardia

- confirm it is sinus tachycardia vs. other rhythms (e.g. atrial fibrillation/flutter, paroxysmal atrial tachycardia, accessory pathway syndromes, ventricular tachycardia)
- causes of sinus tachycardia:
 - shock/hypovolemia/blood loss
 - anxiety/pain/light anesthesia
 - full bladder
 - anemia
 - febrile illness/sepsis
 - drugs (e.g. atropine, cocaine, dopamine, epinephrine, ephedrine, isoflurane, isoproterenol, pancuronium)
 - Addisonian crisis, hypoglycemia, transfusion reaction, malignant hyperthermia

Causes of Intraoperative Bradycardia

- increased parasympathetic tone vs. decreased sympathetic tone
- **must** rule out hypoxemia
- arrhythmias (see *Cardiology and Cardiovascular Surgery*, C12)
- baroreceptor reflex due to increased intracranial pressure or increased blood pressure
- vagal reflex (oculocardiac reflex, carotid sinus reflex, airway manipulation)
- drugs (e.g. succinylcholine, opioids, edrophonium, neostigmine, halothane, digoxin, beta-blockers)
- high spinal/epidural anesthesia



Suspect difficult ventilation with:

BONES

Beard
Obesity/Obstetrics
No teeth
Elderly
Sleep apnea



Causes of Intraoperative Hypoxia

Inadequate oxygen supply: e.g. breathing system disconnection, obstructed or malpositioned ETT, leaks in the anesthetic machine, loss of oxygen supply.

Hypoventilation

Ventilation-perfusion inequalities: e.g. atelectasis, pneumonia, pulmonary edema, pneumothorax.

Reduction in oxygen carrying capacity: e.g. anemia, carbon monoxide poisoning, methemoglobinemia, hemoglobinopathy.

Leftward shift of the hemoglobin-oxygen saturation curve: e.g. hypothermia, decreased 2,3-DPG, alkalosis, hypocarbia, carbon monoxide poisoning.

Right-to-Left cardiac shunt



Hypothermia (32°-35.9°C) Impact on Outcomes

Reduces resistance to wound infections by impairing immune function.

Increases the period of hospitalization by delaying healing.

Reduces platelet function and impairs activation of coagulation cascade increasing blood loss and transfusion requirements.

Tripled the incidence of V-tach and morbid cardiac events.

Decreases the metabolism of anesthetic agents prolonging post-op recovery.

**Intraoperative Shock****SHOCKED**

Sepsis or Spinal shock
Hypovolemic/Hemorrhagic
Obstructive
Cardiogenic
anaphylactic
Extra/other
Drugs



Blood Pressure

Causes of Intraoperative Hypotension/Shock (sBP <90 mmHg or MAP <60 mmHg)

a) hypovolemic/hemorrhagic shock

- see Infectious Diseases, ID24
- most common form of shock, due to blood loss or dehydration
- class 1 hemorrhage: 0-15% of blood volume or <3% total body water (TBW)
 - ♦ decreased peripheral perfusion of organs able to withstand prolonged ischemia (skin, fat, muscle, bone)
 - ♦ patient feels cold, postural hypotension and tachycardia, cool/pale/moist skin, low JVP, decreased CVP, increased peripheral vascular resistance, concentrated urine
 - ♦ treatment: rapidly infuse 1-2 L of balanced salt solutions (BSS), then maintenance fluids
- class 2 hemorrhage: 15-30% of blood volume or approximately 6% of TBW
 - ♦ thirst, supine hypotension and tachycardia, oliguria or anuria
 - ♦ treatment: rapidly infuse 2 L of BSS then re-evaluate continued needs
- class 3 hemorrhage: 30-40% of blood volume
 - ♦ mildly decreased perfusion to heart and brain
 - ♦ marked tachypnea, tachycardia, decreased sBP, oliguria, confusion
 - ♦ treatment: rapidly infuse 2 L of BSS
 - ♦ replace blood losses with BSS (1:3) or PRBCs, colloid (1:1)
 - ♦ maintain urine output >0.5 mL/kg/hr
- class 4 hemorrhage: >40% of blood volume or approximately 9% of TBW
 - ♦ decreased perfusion of heart and brain
 - ♦ agitation, confusion, obtundation, supine hypotension and tachycardia, rapid deep breathing, anuria
 - ♦ treatment: same as class 3

b) obstructive shock

- obstruction of blood into or out of the heart
- increased JVP, distended neck veins, increased systemic vascular resistance, insufficient cardiac output (CO)
- e.g. tension pneumothorax, cardiac tamponade, pulmonary embolism

c) cardiogenic shock

- myocardial dysfunction
- increased JVP, distended neck veins, increased systemic vascular resistance, decreased CO
- e.g. dysrhythmias, ischemia/infarct, cardiomyopathy, acute valvular dysfunction

d) septic shock

- bacterial, viral, fungal, endotoxins/mediators cause vasodilation and capillary leakage
- associated with contamination of open wounds, intestinal injury or penetrating trauma
- fever, decreased JVP, wide pulse pressure, increased cardiac output, increased HR, decreased systemic vascular resistance $\pm$ pressors
- initial treatment: antibiotics, volume expansion

e) spinal/neurogenic shock

- decreased sympathetic tone
- hypotension without tachycardia or peripheral vasoconstriction (warm skin)

f) anaphylactic shock

- see Emergency Medicine, ER30
- acute/subacute generalized allergic reaction due to an inappropriate or excessive immune response (type I hypersensitivity)
 - ♦ treatment
 - moderate reaction: generalized urticaria, angioedema, wheezing, tachycardia
 - epinephrine (1:1000) 0.3-0.5 mg SC
 - antihistamines: diphenhydramine (Benadryl®) 25-50 mg IM
 - salbutamol (Ventolin®) 1 cc via nebulizer
 - severe reaction/evolution: severe wheezing, laryngeal/pulmonary edema, shock
 - ABCs, may need ETT due to airway edema
 - epinephrine (1:1000) 0.1-0.3 mg IV (or via ETT if no IV access) to start, repeat as needed
 - antihistamines: Benadryl® 50 mg IV (~1 mg/kg)
 - steroids: hydrocortisone (Solu-cortef®) 100 mg IV (~1.5 mg/kg) or methylprednisolone (Solumedrol®) 1 mg/kg IV q6h x 24h
 - large volumes of crystalloid may be required

g) drugs

- vasodilators, high spinal anesthetic interfering with sympathetic outflow

h) other

- transfusion reaction, Addisonian crisis, thyrotoxicosis, hypothyroid, aortocaval syndrome

Causes of Intraoperative Hypertension

- pain, anxiety due to inadequate anesthesia
- pre-existing essential hypertension, coarctation or pre-eclampsia
- hypoxemia/hypercarbia
- hypervolemia
- drugs (e.g. ephedrine, epinephrine, cocaine, phenylephrine, ketamine)
- allergic/anaphylactic reaction
- hypermetabolic states: malignant hyperthermia, neuroleptic malignant syndrome (see Psychiatry, PS44), pheochromocytoma, thyroid storm (see Endocrinology, E35, E25)

Fluid Balance and Resuscitation



- TOTAL REQUIREMENT = MAINTENANCE + DEFICIT + ONGOING LOSS
- in surgical settings this formula must take into account multiple factors including pre-operative fasting/decreased fluid intake, increased losses during or before surgery, fluid shifting during surgery, fluids given with blood products and medications

What is the Maintenance?

- average healthy adult requires approximately 2500 mL water/day
 - 200 mL/day GI losses
 - 800 mL/day insensible losses (respiration, perspiration)
 - 1500 mL/day urine (beware of renal failure)
- increased requirements with fever, sweating, GI losses (vomiting, diarrhea, NG suction), adrenal insufficiency, hyperventilation, and polyuric renal disease
- decreased requirements with anuria/oliguria, SIADH, highly humidified atmospheres, and CHF
- 4:2:1 rule to calculate maintenance requirements (applies to crystalloids only)
 - 4 mL/kg/hour first 10 kg
 - 2 mL/kg/hour second 10 kg
 - 1 mL/kg/hour for remaining weight >20 kg
- maintenance electrolytes
 - Na: 3 mEq/kg/day
 - K: 1 mEq/kg/day
- e.g. 50 kg patient maintenance requirements
 - fluid = $40 + 20 + 30 = 90$ mL/hour = 2160 mL/day
 - Na = 150 mEq/day (therefore 66 mEq/L)
 - K = 100 mEq/day (therefore 22 mEq/L)
- above patient's requirements roughly met with 2/3 D5W, 1/3 NS
 - e.g. 2/3 + 1/3 @ 100 mL/hour with 20 mEq KCl per litre

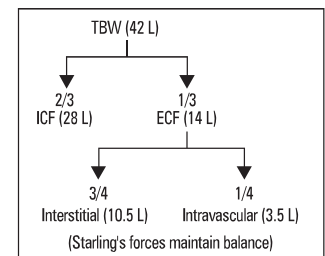


Figure 7. Total Body Water Division in a 70 kg Adult

What is the Deficit?

- patients should be adequately hydrated prior to anesthesia
- TBW = 60% or 50% of total body weight for an adult male or female, respectively (e.g. for a 70 kg adult male TBW = $70 \times 0.6 = 42$ L)
- total Na content determines ECF volume, [Na] determines ICF volume
- hypovolemia due to volume contraction
 - extra-renal Na loss
 - ♦ GI: vomiting, NG suction, drainage, fistulae, diarrhea
 - ♦ skin/resp: insensible losses (fever), sweating, burns
 - ♦ vascular: hemorrhage
 - renal Na and H₂O loss
 - ♦ diuretics
 - ♦ osmotic diuresis
 - ♦ hypoaldosteronism
 - ♦ salt-wasting nephropathies
 - renal H₂O loss
 - ♦ diabetes insipidus (central or nephrogenic)
 - hypovolemia with normal or expanded ECF volume
 - ♦ decreased cardiac output
 - ♦ redistribution
 - hypoalbuminemia: cirrhosis, nephrotic syndrome
 - capillary leakage: acute pancreatitis, rhabdomyolysis, ischemic bowel, sepsis, anaphylaxis
- replace water and electrolytes as determined by patient's needs
- with chronic hyponatremia correction must be done gradually over >48 hours to avoid CNS central pontine myelinolysis

Table 4. Signs and Symptoms of Dehydration

Percentage of Body Water Loss	Severity	Signs and Symptoms
3%	Mild	Decreased skin turgor, sunken eyes, dry mucous membranes, dry tongue, reduced sweating
6%	Moderate	Oliguria, orthostatic hypotension, tachycardia, low volume pulse, cool extremities, reduced filling of peripheral veins and CVP, hemoconcentration, apathy
9%	Severe	Profound oliguria or anuria and compromised CNS function with or without altered sensorium

What are the Ongoing Losses?

- tubes
 - Foley catheter, NG, surgical drains
- third spacing (other than ECF, ICF)
 - pleura, GI, retroperitoneal, peritoneal
 - evaporation via exposed viscera, burns
- blood loss
- ongoing loss due to surgical exposure and evaporative losses
 - minor surgery 3 cc/kg/hr e.g. laparoscopic surgery
 - intermediate surgery 6 cc/kg/hr e.g. open cholecystectomy
 - major surgery 9 cc/kg/hr e.g. abdominal aneurysm repair

IV Fluids

- replacement fluids include crystalloid and colloid solutions
- improves perfusion but NOT O₂ carrying capacity of blood

Crystalloid Infusion

- salt-containing solutions that distribute within ECF
- maintain euvolemia in patient with blood loss: 3 mL crystalloid infusion per 1 mL of blood loss for volume replacement (i.e. 3:1 replacement). Controversy surrounds this as an initial vs. maximal replacement target
- after 3 L crystalloid replacement, switch to pRBCs
- if large volumes are to be given, use balanced fluids such as Ringer's lactate or Plasmalyte[®], as too much normal saline (NS) may lead to hyperchloremic metabolic acidosis

Colloid Infusion (see *Blood Products*, A15)

- collected from donor blood (fresh frozen plasma, albumin, RBCs) or synthetics [e.g. hydroxyethyl starch (HES) solutions]
- distributes within intravascular volume
- 1:1 ratio (infusion: blood loss) only in terms of replacing volume
- HES colloids remain in intravascular space (metabolized by plasma serum amylase and renally excreted), two available in Canada: Voluven[®] and Pentaspan[®]

Table 5. Colloid HES Solutions

	Concentration	Plasma Volume Expansion	Duration (h)	Maximum Daily Dose (ml/kg)
Voluven [®]	6%	1:1	4-6	33-50
Pentaspan [®]	10%	1:1.2-1.5	18-24	28

Initial Distribution of IV Fluids

- H₂O follows ions/molecules to their respective compartments

Table 6. IV Fluid Solutions

		ECF	Ringer's Lactate	0.9 NS	0.45 NS	D5W	2/3 + 1/3	Plasmalyte
mEq/L	Na	142	130	154	77	-	51	140
	K	4	4	-	-	-	-	5
	Ca	4	3	-	-	-	-	-
	Mg	3	-	-	-	-	-	3
	Cl	103	109	154	77	-	51	98
	HCO ₃	27	28*	-	-	-	-	27
mOsm/L		280-310	273	308	407	253	269	294

*Converted from lactate

Colloids versus Crystalloids for Fluid Resuscitation in Critically Ill Patients*Cochrane Library* 2009; Issue 3.

Purpose: To evaluate the effects of colloids compared to crystalloids for fluid resuscitation, specifically when used in critically ill patients.

Methods: A meta-analysis was performed looking at randomized controlled trials comparing colloid vs. crystalloids in use with patient requiring fluid resuscitation due to traumatic injury (including burns) or post surgery. Pregnant women and neonates were excluded. Primary outcome was overall mortality.

Results: Results are broken down based on specific colloid. For albumin (or plasma protein fraction) the relative risk (RR) was 1.00 (95% CI 0.91 - 1.10), as compared to crystalloid. For hydroxyethyl starch the RR was 1.18 (95% CI 0.96 - 1.44). Modified gelatin had a RR of 0.91 (95% CI 0.49 - 1.72) and Dextran had a RR of 1.24 (95% CI 0.94 - 1.65). For colloids mixed in a hypertonic crystalloid as compared to isotonic crystalloid the RR was 0.88 (95% CI 0.74 - 1.05).

Conclusions: There is no evidence that use of colloids improves survival in trauma patients, burn patients or post-operative patients, when compared to crystalloid solutions. Given the increased cost of colloids as compared to crystalloids, it is recommended that crystalloids be the fluid of choice in these patients.

Blood Products

- see [Hematology](#), H50

Table 7. Blood Products

Red Blood Cells (RBCs) (U = unit)	• 1 U RBCs = approx. 300 mL • 1 U RBCs increases Hb by approx. 10 g/L in a 70 kg patient • RBCs may be diluted with colloid/crystalloid to decrease viscosity • Decision to transfuse based on initial blood volume, premorbid Hb level, present volume status, expected further blood loss, patient health status • MASSIVE transfusion = $>1 \times$ blood volume/24 hours
Autologous RBCs	• Replacement of blood volume with one's own RBCs • May decrease complications (infectious, febrile, etc.) • Alternative to homologous transfusion in elective procedures, but only if adequate Hb and no infection • Pre-op phlebotomy prior to elective surgery (up to 4 U collected >1 week before surgery) • Intraoperative salvage and filtration (cell saver); contraindicated in dirty cases
Non-RBC Products	• Fresh frozen plasma (FFP) ▪ Contains all plasma clotting factors and fibrinogen close to normal plasma levels ▪ To prevent/treat bleeding due to coagulation factor depletion/deficiencies, liver impairment • Cryoprecipitate ▪ Contains Factors VIII and XIII, vWF, fibrinogen • Platelets ▪ Used in thrombocytopenia, massive transfusions, impaired platelet function • Albumin ▪ Selective intravascular volume expander • Erythropoietin ▪ Can be used pre-operatively to stimulate erythropoiesis



Calculating Acceptable Blood Losses (ABL)

- Blood volume

term infant	80 mL/kg
adult male	70 mL/kg
adult female	60 mL/kg
- Calculate estimated blood volume (EBV) (e.g. in a 70 kg male, approx. 70 mL/kg)
 $EBV = 70 \text{ kg} \times 70 \text{ mL/kg} = 4900 \text{ mL}$
- Decide on a transfusion trigger, i.e. the Hb level at which you would begin transfusion, (e.g. 70 g/L for a person with Hb(i) = 150 g/L)
 $Hb(f) = 70 \text{ g/L}$
- Calculate

$$ABL = \frac{Hb(i) - Hb(f)}{Hb(i)} \times EBV$$

$$= \frac{150 - 70}{150} \times 4900 = 2613 \text{ mL}$$
- Therefore in order to keep the Hb level above 70 g/L, RBCs would have to be given after approximately 2.6 L of blood has been lost.

Transfusion Reactions

Immunosuppression

- some studies show associations between peri-operative transfusion and post-operative infection, earlier cancer recurrence, and poorer outcome

Nonimmune

- infectious risks: HIV, hepatitis B/C, Epstein-Barr virus (EBV), cytomegalovirus (CMV), brucellosis, malaria, salmonellosis, measles, syphilis
- hypervolemia
- electrolyte changes: increased K in stored blood
- dilutional coagulopathy
- dilutional thrombocytopenia
- hypothermia
- citrate toxicity
- hypocalcemia
- iron overload

A Multicenter, Randomized, Controlled Clinical Trial of Transfusion Requirements in Critical Care
NEJM 1999; 340: 409-417

Purpose: To determine whether a restrictive strategy of RBC transfusion and a liberal strategy produce equivalent results in critically ill patients.

Study: Randomized controlled trial with 60 day follow-up.

Patients: 838 critically ill patients with euolemia after initial treatment who had Hb concentrations of less than 90 g/L within 72 hours after admission to the ICU. Mean age 57.5 years, 62.5% male.

Intervention: Patients were randomly assigned to either a restrictive strategy of transfusion, in which RBC were transfused if the Hb dropped <70 g/L and Hb concentrations were maintained between 70-90 g/L, or to a liberal strategy, in which transfusions were given when the Hb dropped <100 g/L and Hb concentrations were maintained between 100-120 g/L.

Main Outcomes: All cause mortality rates at 30 and 60 days, mortality rates during the stay in ICU and hospitalization, survival times during the first 30 days, and rates of organ failure and dysfunction.

Results: Overall, 30-day mortality was similar in the two groups. However, the rates were significantly lower with the restrictive transfusion strategy among patients who were less acutely ill (8.7% vs. 16.1%) and who were less than 55 years of age (5.7% vs. 13%), but not among patients with clinically significant cardiac disease.

The mortality rate during hospitalization was significantly lower in the restrictive-strategy group (22.2% vs. 28.1%).

Conclusions: A restrictive strategy of RBC transfusion is at least as effective as, and possibly superior to, a liberal transfusion strategy in critically ill patients, with the possible exception of patients with acute MI and unstable angina.

Table 8. Immune Transfusion Reactions

Reaction	Cause	Presentation	Management
Non-hemolytic: Febrile	Alloantibodies to WBC, platelet, or other donor plasma antigens	- Mild fever <38°C with or without rigors; may be > 38°C with restlessness and shivering - Nausea, facial flushing, headache, myalgias, hypotension, chest and back pain - Occurs quickly; near completion of transfusion or within 2 hours 1 in 100	- Rule out fever due to hemolytic reaction or bacterial contamination - Mild (<38°C): decrease infusion rate and give antipyretics - Severe: stop transfusion, give antipyretics, antihistamines, and symptomatic treatment
Non-hemolytic: Allergic	- Mild allergic reaction due to IgE alloantibodies to substances in donor plasma - Mast cells activated with histamine release - Usually occurs in pre-exposed (e.g. multiple transfusions, multiparous)	- Often have history of similar reactions - Abrupt onset pruritic erythema/urticaria on arms and trunk, occasionally with fever - Less common: involvement of face, larynx and bronchioles 1 in 100	- Mild: slow transfusion rate, IV antihistamines - Moderate to severe: stop transfusion, IV antihistamines, subcutaneous epinephrine, hydrocortisone, IV fluids, bronchodilators - Prophylactic: antihistamines 15-60 minutes prior to transfusion, washed or deglycerolized frozen RBC
Non-hemolytic: Anaphylactoid	- In IgA deficient patients with anti-IgA antibodies receiving IgA-containing blood - Immune complexes activate mast cells, basophils, eosinophils, and complement system = severe symptoms after transfusion of RBC, plasma, platelets, or other components with IgA	- Rare, potentially lethal - Apprehension, urticarial eruptions, dyspnea, hypotension, laryngeal and airway edema, wheezing, chest pain, shock, sudden death	- Circulatory support with fluids, catecholamines (epinephrine), bronchodilators - Respiratory assistance as indicated - Evaluate for IgA deficiency and anti-IgA antibodies - Future transfusions must be free of IgA: washed/deglycerolized RBCs free of IgA, blood from IgA deficient donor
Transfusion Related Acute Lung Injury (TRALI)	- Form of noncardiogenic pulmonary edema - Immunologic cause; not due to fluid overload or cardiac failure - Binding of donor Ab against recipient WBC causing cytokine release leading to increased capillary permeability	- Occurs 2-4 hours post transfusion - Respiratory distress: mild dyspnea to severe hypoxia - Chest x-ray: consistent with acute pulmonary edema, but pulmonary artery and wedge pressures are not elevated 1 in 5000	Usually resolves within 48 hrs with O₂, mechanical ventilation, supportive treatment
Hemolytic Acute (intravascular hemolysis)	- Caused by donor incompatibility with recipient's blood - Often due to clerical error - Antibody coated RBC is destroyed by activation of complement system - ABO incompatibility common cause, other RBC Ag-Ab systems can be involved	- Fever, chills, chest or back pain, hypotension, tachycardia, nausea, flushing, dyspnea, wheezing, hypoxemia, hemoglobinuria, diffuse bleeding due to DIC, acute renal failure <1 in 250 000	- Stop transfusion - Notify blood bank, confirm or rule out diagnosis – clerical check, direct Coombs', repeat grouping, Rh screen and crossmatch, serum haptoglobin - Manage hypotension with fluids, inotropes, other blood products - Maintain urine output with crystalloids, furosemide, dopamine, alkalinize urine - Component treatment if DIC, repeat grouping, Rh screen and crossmatch, serum haptoglobin - Manage hypotension with fluids, inotropes, other blood products - Component treatment (e.g. FFP, cryoprecipitate)
Hemolytic Delayed (extravascular hemolysis)	- Caused by donor incompatibility with recipient's blood - Generally mild, caused by antibodies to Rh system, Kell, Duffy, or Kidd antigens - The level of antibody at the time of transfusion is too low to be detected or to cause hemolysis, later the level of antibody is increased due to secondary stimulus	- Occurs in recipients sensitized to RBC antigens by previous blood transfusion or pregnancy - Anemia, mild jaundice, fever 1 to 21 days post transfusion	- Supportive - Direct Coombs, a reexamination of pretransfusion specimens from the patient and donor for diagnosis

Extubation

- performed by trained, experienced personnel because reintubation may be required
- criteria
 - patient must no longer have intubation requirements
 - patency: airway must be patent
 - protection: patient must have intact airway reflexes
 - patient must be oxygenating and ventilating spontaneously
- laryngospasm more likely in semiconscious patient; must ensure adequate LOC
- general guidelines
 - ensure patient has normal neuromuscular function and hemodynamic status
 - ensure patient is breathing spontaneously with adequate rate and tidal volume
 - allow ventilation (spontaneous or controlled) with 100% O₂ for 3-5 minutes
 - suction secretions from pharynx
 - deflate cuff, remove ETT on inspiration (vocal cords abducted)
 - ensure patient is breathing adequately after extubation
 - ensure face mask for O₂ delivery available
 - proper positioning of patient during transfer to recovery room (e.g. lateral decubitus, head elevated)

Complications of Extubation

- early
 - aspiration
 - laryngospasm
- late
 - transient vocal cord incompetence
 - edema (glottic, subglottic)
 - pharyngitis, tracheitis

Post-Operative Care

- pain management should be continuous from OR to post-anesthetic unit (PAU) to hospital ward and home
- pain service may assist with management of post-operative inpatients

Post-Operative Nausea and Vomiting (PONV)

- hypotension and bradycardia must be ruled out
- pain and surgical manipulation also cause nausea
- often treated with dimenhydrinate (Gravol®), metoclopramide (Maxeran®) (not with bowel obstruction), prochlorperazine (Stemetil®), ondansetron (Zofran®), granisetron (Kytril®)

Post-Operative Confusion and Agitation

- ABCs first! – confusion or agitation can be caused by airway obstruction, hypercapnea, hypoxemia
- neurologic status (Glasgow Coma Scale, pupils), residual paralysis from anesthetic
- pain, distended bowel/bladder
- fear/anxiety/separation from caregivers/language barriers
- metabolic disturbance (hypoglycemia, hypercalcemia, hyponatremia – especially post-TURP)
- intracranial cause (stroke, raised intracranial pressure)
- drug effect (ketamine, anticholinergics)
- elderly patients are more susceptible to post-operative delirium

Pain Management

Definitions

- nociception: detection, transduction and transmission of noxious stimuli
- pain: perception of nociception which occurs in the brain

Acute Pain

- pain of short duration (<6 weeks) usually associated with surgery, trauma or acute illness; often associated with inflammation
- usually limited to the area of damage/trauma and resolves with healing



Risk Factors for Post-Operative Nausea and Vomiting (PONV)

1. Young age
2. Female
3. History of PONV
4. Non-smoker
5. Type of surgery: ophtho, ENT, abdo/pelvic, plastics
6. Type of anesthetic: N₂O, opioids, volatile agents

Drugs for Preventing Post-Operative Nausea and Vomiting.

Cochrane Library 2008; Issue 4.

Purpose: To evaluate the efficacy of antiemetics in preventing nausea and vomiting in post-operative patients.

Methods: A meta-analysis was performed looking at randomized controlled trials comparing an antiemetic to either a second antiemetic or placebo. Trials looking at dosing and/or timing of medication administration were also included. Post-operative nausea or vomiting was used as the primary outcome.

Results: 737 studies involving 103 237 patients. Eight drugs significantly reduced the occurrence of post-operative nausea and vomiting, namely: droperidol, metoclopramide, ondansetron, tropisetron, dolasetron, dexamethasone, cyclizine and granisetron. Relative risk (RR) versus placebo varied between 0.60 and 0.80. Side effects included a significant increase in drowsiness for droperidol (RR 1.32) and headache for ondansetron (1.16). The cumulative number needed to treat was 3.57.

Conclusion: Antiemetic medication is effective for reducing the occurrence of post-operative nausea and vomiting. However, further investigation needs to be done to determine whether antiemetics can cause more severe (and likely rare) side-effects, which could alter how liberally they are used.

**WHO Analgesia Ladder****Mild Pain**

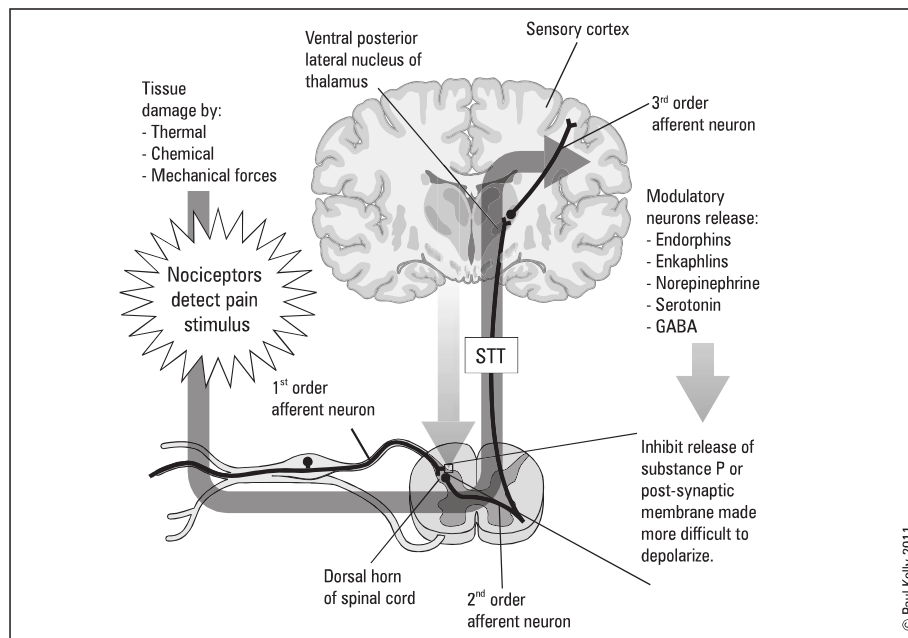
Acetaminophen
NSAIDS

Moderate Pain

Codeine
Oxycodone

Severe Pain

Oxycodone
Morphine
Hydromorphone
Fentanyl

**Figure 8. Acute Pain Mechanism****Pharmacological Management of Acute Pain**

- ask the patient to rate the pain out of 10, or using visual analog scale, to determine severity

Table 9. Commonly Used Analgesics

	Acetaminophen	NSAIDs	Opioids
Examples	Tylenol®	- Aspirin®, ibuprofen, naproxen - ketorolac (IV)	- Oral: codeine, oxycodone, morphine, hydromorphone - Parenteral: morphine, hydromorphone, fentanyl
Indications	First-line for mild acute pain	Mild-moderate pain	- Oral: mild and moderate acute pain - Parenteral: severe acute pain
Mechanism of Action	? Cyclooxygenase-2 (COX-2) inhibition ? Modulation of endogenous cannabinoid system	Non-selective COX-1 and -2 inhibition reducing proinflammatory prostaglandin synthesis	- Dampens nociceptive transmission between 1st and 2nd order neurons in the dorsal horn - Activates ascending modulatory pathways resulting in release of inhibitory neurotransmitters - Inhibits peripheral inflammatory response and hyperalgesia - Affects mood and anxiety – alleviates the affective component of perceived pain
Dosing/Administration	- Limited by analgesic ceiling beyond which there is no additional analgesia - Opioid-sparing - Max dose of 4 g/24hrs	- Limited by analgesic ceiling beyond which there is no additional analgesia - Opioid-sparing - Significant inter-individual variation in efficacy	- No analgesic ceiling (except for codeine) - Can be administered intrathecal (spinal block) or by continuous infusion - See <i>Clinical Pharmacology</i>, CP14 for opioid analgesic equivalencies
Side Effects/Toxicity	- Considered relatively safe - Liver toxicity in elevated doses	- Gastric ulceration/bleeding - Decreased renal perfusion - Photosensitivity - Premature closure of the ductus arteriosus in pregnancy	- Respiratory depression - Constipation and abdominal pain - Sedation - Nausea and vomiting - Pruritus - Confusion (particularly in the elderly)

- patient controlled analgesia (PCA)
 - involves the use of computerized pumps that can deliver a constant infusion as well as bolus breakthrough doses of parenterally-administered opioid analgesics
 - limited by lockout intervals
 - most commonly used agents: morphine and hydromorphone
 - refer to Table 12 for suggested infusion rate, PCA dose, and lockout intervals

**Use NSAIDs with Caution in Patients with:**

- Asthma
- Coagulopathy
- GI ulcers
- Renal insufficiency
- Pregnancy, 3rd trimester

**Common Side Effects of Opioids**

- Nausea and vomiting
- Constipation
- Sedation
- Pruritis
- Abdominal pain
- Urinary retention
- Respiratory depression

**PCA Parameters**

- Loading dose
- Bolus dose
- Lockout interval
- Continuous infusion (optional)
- Max. 4 hr limit (optional)

**Advantages of PCA**

Better pain control
Fewer side effects
Accommodates patient variability
Accommodates changes in opioid requirements

Opioid Antagonists (naloxone, naltrexone)

- opioid overdose manifests primarily at CNS (e.g. respiratory depression) – manage ABCs
- opioid antagonists competitively inhibit opioid receptors, predominantly Mu (μ) receptors
- naloxone is short acting ($t_{1/2}$ = 1 hr); effects of narcotic may return when naloxone wears off, therefore the patient must be observed closely following its administration
- naltrexone is longer acting ($t_{1/2}$ = 10 hrs); less likely to see return of narcotic effects
- relative overdose of naloxone may cause nausea, agitation, sweating, tachycardia, hypertension, re-emergence of pain, pulmonary edema, seizures (essentially opioid withdrawal)

Regional Anesthesia



Definition of Regional Anesthesia

- local anesthetic agent (LA) applied around a peripheral nerve at any point along the length of the nerve (from spinal cord up to, but not including, the nerve endings) for the purposes of reducing or preventing impulse transmission
- no CNS depression (unless overdose of local anesthetic); patient conscious
- regional anesthetic techniques categorized as follows:
 - epidural and spinal anesthesia (neuraxial anesthesia)
 - peripheral nerve blockades
 - IV regional anesthesia (e.g. Bier block)

Preparation for Regional Anesthesia

Patient Preparation

- thorough pre-operative evaluation and assessment of patient
- technique explained to patient
- IV sedation may be indicated before block
- monitoring should be as extensive as for general anesthesia

Relative Indications for Regional Anesthesia

- avoids some of the dangers of general anesthesia, e.g. known difficult intubation, severe respiratory failure, etc.
- patient specifically requests regional anesthesia
- high quality post-operative pain relief
- general anesthesia not available/contraindicated
- titration of LA dosage for differential blockade, e.g. can block pain but preserve motor function

Complications of Regional Anesthesia

- failure of technique/inadequate anesthesia
- systemic drug toxicity due to overdose or intravascular injection
- injury to muscle, ligament or bone (back pain), to nerve root/spinal cord (nerve deficit), to epidural vein (hematoma)
- infection (e.g. osteitis, epidural abscess, meningitis)
- spinal and epidural: sympathetic blockade causing hypotension and bradycardia (occurs early, followed by sensory then motor blockade)

Epidural and Spinal Anesthesia

Anatomy of Spinal/Epidural Area (Figure 9)

- spinal cord extends to L2, dural sac to S2 in adults
- nerve roots (cauda equina) from L2 to S2
- needle inserted below L2 should not encounter cord, thus L3-L4, L4-L5 interspace commonly used
- structures penetrated
 - skin
 - subcutaneous fat
 - supraspinous ligament
 - interspinous ligament
 - ligamentum flavum (last layer before epidural space)
 - dura + arachnoid for spinal anesthesia

Patient Controlled Opioid Analgesia versus Conventional Opioid Analgesia for Postoperative Pain.

Cochrane Library 2009; Issue 1.

Purpose: To evaluate the efficacy of patient controlled analgesia (PCA) as compared to conventional 'as-needed' analgesia administration providing pain relief in post-operative patients.

Methods: Meta-analyses of randomised controlled trials comparing PCA versus conventional administration of opioid analgesia. Assessment employed a visual analog scale (VAS) for pain intensity along with overall analgesic consumption, patient satisfaction, length of stay and adverse side-effects.

Results: 55 studies with a total of 2023 patients receiving PCA and 1838 patients with standard as-needed opioid administration. PCA provided significantly better pain control through 72 hours post-operatively, but patients consumed significantly more opioids (+7 mg morphine / 24 hr, $P < 0.05$). Significantly more patients reported pruritis in the PCA group compared to control with a number needed to harm of 13. No significant difference in overall length of stay in hospital, sedation level, nausea/vomiting or urinary retention.

Conclusions: Patient controlled opioid analgesia is more effective than standard as-needed administration for reducing post-operative pain. However, patients using PCA consume more opioids overall and have more pruritis.

**Benefits of Regional Anesthesia**

- Reduced peri-op pulmonary complications
- Reduced peri-op analgesia requirements
- Decreased PONV
- Reduced peri-op blood loss
- Ability to monitor CNS status during procedure
- Improved perfusion
- Lower incidence of VTE

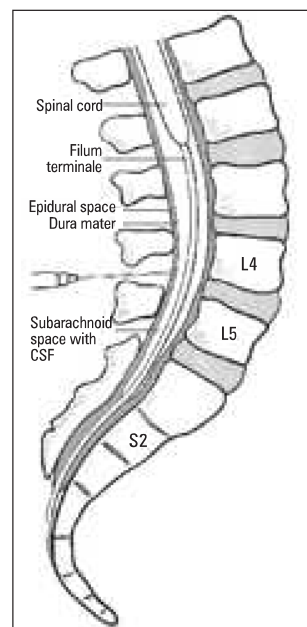


Figure 9. Landmarks for Placement of Epidural/Spinal



Landmarking Epidural/Spinal Anesthesia

Spinous processes should be maximally flexed

L4 spinous processes found between iliac crests

Common sites of insertion are L3-L4 and L4-L5



Classic Presentation of Dural Puncture Headache

1. Onset 6 hrs – 3 days after dural puncture
2. Postural component (worse sitting)
3. Occipital or frontal localization
4. $\pm$ tinnitus, diplopia

Reduction of Postoperative Mortality and Morbidity with Epidural or Spinal Anaesthesia: Results from Overview of Randomised Trials

BMJ 2000; 321:1-12

Purpose: To obtain reliable estimates of the effects of neuraxial blockade with epidural or spinal anesthesia on postoperative morbidity and mortality.

Study: Systematic review of all trials with randomization to intra-operative neuraxial blockade versus not.

Patients: 141 trials including 9559 patients.

Main Outcomes: All cause mortality, MI, PE, DVT, transfusion requirements, pneumonia, other infections, respiratory depression, and renal failure.

Results: Overall mortality was reduced by about a third in patients allocated to neuraxial blockade. Neuraxial blockade reduced the risk of PE by 55%, DVT by 44%, transfusion requirements by 50%, pneumonia by 39%, and respiratory depression by 59%. There were also reductions in MI and renal failure. The proportional reductions in mortality did not clearly differ by surgical group, type of blockade (epidural or spinal), or in those trials in which neuraxial blockade was combined with general anesthesia compared with trials in which neuraxial blockade was used alone.

Conclusions: Neuraxial blockade reduces postoperative mortality and other serious complications.

Table 10. Epidural versus Spinal Anesthesia

	Epidural	Spinal
Deposition Site	LA deposited in epidural space (space between ligamentum flavum and dura) Initial blockade is at the spinal roots followed by some degree of spinal cord anesthesia as LA diffuses into the subarachnoid space through the dura	LA injected into subarachnoid space in the dural sac surrounding the spinal cord and nerve roots
Onset	Significant blockade requires 10-15 minutes Slower onset of side effects	Rapid blockade (onset in 2-5 minutes)
Effectiveness	Effectiveness of blockade can be variable	Very effective blockade
Difficulty	Technically more difficult; greater failure rate	Easier to perform due to visual confirmation of CSF flow
Patient Positioning	Position of patient not as important; specific gravity not an issue	Hyperbaric LA solution – position of patient important
Specific Gravity/Spread	Solutions injected here spread throughout the potential space; specific gravity of solution does not affect spread	LA solution may be made hyperbaric (of greater specific gravity than the cerebrospinal fluid by mixing with 10% dextrose, thus increasing spread of LA to the dependent (low) areas of the subarachnoid space)
Dosage	Larger volume/dose of LA (usually > toxic IV dose)	Smaller dose of LA required (usually < toxic IV dose)
Continuous Infusion	Use of catheter allows for continuous infusion or repeat injections	None
Complications	Failure of technique Hypotension Bradycardia if cardiac sympathetics blocked (only if ~T2-4 block) Epidural or subarachnoid hematoma Accidental subarachnoid injection can produce spinal anesthesia (and any of the above complications) Systemic toxicity of LA (accidental intravenous) Catheter complications (shearing, kinking, vascular or subarachnoid placement) Infection Dural puncture	Failure of technique Hypotension Bradycardia if cardiac sympathetics blocked (only if ~T2-4 block), i.e. "high spinal" Epidural or subarachnoid hematoma Post-spinal headache (CSF leak) Persistent paresthesias (usually transient) Spinal cord trauma, infection
Combined Spinal-Epidural	Combines the benefits of rapid, reliable, intense blockade of spinal anesthesia together with the flexibility of an epidural catheter	

LA = Local anesthetic agent

Contraindications to Spinal/Epidural Anesthesia

- absolute contraindications
 - lack of proper equipment or properly trained personnel
 - lack of IV access
 - allergy to LA
 - infection at puncture site or underlying tissues
 - coagulopathies
 - raised ICP
 - sepsis/bacteremia
 - hemodynamic instability/uncorrected hypovolemia
- relative contraindications
 - bacteremia
 - pre-existing neurological disease
 - aortic/mitral valve stenosis (i.e. fixed cardiac output states)
 - previous spinal surgery, severe kyphoscoliosis
 - severe/unstable psychiatric disease or emotional instability

Peripheral Nerve Blocks

- generally used for post-operative analgesia; sometimes uses for intra-operative anesthesia
- relatively safe
- 2 cardinal rules: 1. Avoid intraneural injection 2. Avoid neurotoxic agents
- e.g. brachial plexus block, femoral nerve block, digital ring block, etc.
- can be ultrasound-guided to prevent neural injury

Contraindications to Peripheral Nerve Blockade

- allergy to local anesthetic (LA)
- patient refusal, lack of cooperation
- lack of resuscitation equipment
- lack of IV access
- certain types of pre-existing neurological dysfunction (e.g. ALS, MS)
- local infection at block site

Local Anesthesia

Local Anesthetic Agents (LA)

- see Table 17 for list of local anesthetic agents

Definition and Mode of Action

- LA are drugs that block the generation and propagation of impulses in excitable tissues: nerves, skeletal muscle, cardiac muscle, brain
- LA bind to receptor (on the cytosolic side of the Na channel, i.e. lipid soluble), inhibiting Na flux and thus blocking impulse conduction
- different types of nerve fibres undergo blockade at different rates

Absorption, Distribution, Metabolism

- LA readily crosses the blood-brain barrier (BBB) once absorbed into the bloodstream
- **ester-type** LA (procaine, tetracaine) are broken down by plasma and hepatic esterases; metabolites excreted via kidneys
- **amide-type** LA (lidocaine, bupivacaine) are broken down by hepatic mixed-function oxidases (P450 system); metabolites excreted via kidneys

Selection of LA

- choice of LA depends on
 - onset of action: influenced by pKa (the lower the pKa, the higher the concentration of the base form of the LA and the faster the onset of action)
 - duration of desired effects: influenced by protein binding (longer duration of action when protein binding of LA is strong)
 - potency: influenced by lipid solubility (agents with high lipid solubility penetrate the nerve membrane more easily)
 - unique needs (e.g. sensory blockade with relative preservation of motor function by bupivacaine at low doses)
 - potential for toxicity

Systemic Toxicity

- see Table 17 for max doses, potency and duration of action for common LA agents
- occurs by accidental intravascular injection, LA overdose, or unexpectedly rapid absorption
- CNS effects first appear to be excitatory due to initial block of inhibitory fibres; then subsequent block of excitatory fibres
- CNS effects (in order of appearance) (Figure 10)
 - numbness of tongue, perioral tingling, metallic taste
 - disorientation, drowsiness
 - tinnitus
 - visual disturbances
 - muscle twitching, tremors
 - unconsciousness
 - convulsions, seizures
 - generalized CNS depression, coma, respiratory arrest
- CVS effects
 - vasodilation, hypotension
 - decreased myocardial contractility

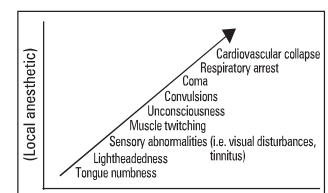


Figure 10. Local Anesthetic Systemic Toxicity

- dose-dependent delay in cardiac impulse transmission
 - ♦ prolonged PR, QRS intervals
 - ♦ sinus bradycardia
- CVS collapse
- treatment of systemic toxicity
 - early recognition of signs
 - 100% O₂, manage ABCs
 - diazepam or sodium thiopental may be used to increase seizure threshold
 - if the seizures are not controlled by diazepam or thiopental, consider using succinylcholine (stops muscular manifestations of seizures, facilitates intubation)
 - manage arrhythmias
 - consider Intralipid® 20% to bind local anesthesia in circulation

Local Infiltration, Hematoma Blocks

Local Infiltration

- injection of tissue with local anesthetic agent (LA), producing a lack of sensation in the infiltrated area due to LA acting on nerve endings
- suitable for small incisions, suturing, excising small lesions
- can use fairly large volumes of dilute LA to infiltrate a large area
- low concentrations of epinephrine (1:100,000-1:200,000) cause vasoconstriction, thus reducing bleeding and prolonging the effects of LA by reducing systemic absorption

Fracture Hematoma Block

- special type of local infiltration for pain control during manipulation of certain fractures
- hematoma created by fracture is infiltrated with LA to anesthetize surrounding tissues
- sensory blockade may be only partial
- no muscle relaxation

Topical Anesthetics

- various preparations of local anesthetics available for topical use, may be a mixture of agents, e.g. EMLA cream is a combination of 2.5% lidocaine and prilocaine
- must be able to penetrate the skin or mucous membrane

Obstetrical Anesthesia

Physiologic Changes in Pregnancy

1. **airway**
 - upper airway becomes edematous and friable
 - decreased FRC and increased O₂ consumption → desaturation
2. **cardiovascular system**
 - increased blood volume > increased RBC mass → mild anemia
 - decreased SVR proportionately greater than increased CO → decreased BP
 - prone to decreased BP due to aortocaval compression
3. **central nervous system**
 - decreased MAC due to hormonal effects
 - increased block height due to engorged epidural veins
4. **gastrointestinal system**
 - delayed gastric emptying
 - increased volume and acidity of gastric fluid
 - decreased LES tone
 - increased abdominal pressure
 - combined, these lead to an increased risk of aspiration

Options for Analgesia during Labour

1. **psychoprophylaxis** – Lamaze method
 - patterns of breathing and focused attention on fixed object
2. **systemic medication**
 - easy to administer, but risk of maternal or neonatal depression
 - common drugs: opioids (morphine, meperidine)
3. **inhalational analgesia**
 - easy to administer, makes uterine contractions more tolerable, but does not relieve pain completely
 - 50% nitrous oxide



Where Not to Use Local Anesthetic Agent (LA) with Epinephrine
 “Fingers, Toes, Penis, Nose”

The Effect of Epidural Analgesia on Labour, Maternal, and Neonatal Outcomes: A Systematic Review

Am J Obstet Gynecol 2002; 186:S69-77

Study: Meta-analysis of 14 studies with 4324 women.

Selection Criteria: Randomized controlled trials and prospective cohort studies between 1980-2001 comparing epidural analgesia to parenteral opioid administration during labour.

Types of Participants: Healthy women with uneventful pregnancies.

Intervention: Participants were randomized to either epidural analgesia or parenteral opioid administration during labour.

Outcomes and Results: Maternal – there were no differences between the 2 groups in first-stage labour length, incidence of Caesarean delivery, incidence of instrumented vaginal delivery for dystocia, nausea, or mid-to-low back pain post-partum. However, second-stage labour length was longer (mean=15 min) and there were greater reports of fever and hypotension in the epidural group. Also, lower pain scores and greater satisfaction with analgesia were reported among the epidural group. There was no difference in lactation success at 6 weeks and urinary incontinence was more frequent in the epidural group immediately post-partum, but not at 3 months or 1 year (evidence from PC studies only). Neonatal – there were no differences between the 2 groups for incidence of fetal heart rate abnormalities, intrapartum meconium, poor 5-min Apgar score, or low umbilical artery pH. However, the incidence of poor 1-min Apgar scores and need for neonatal naloxone were higher in the parenteral opioid group.

Conclusions: Epidural analgesia is a safe intrapartum method for labour pain relief and women should not avoid epidural analgesia for fear of neonatal harm, Caesarean delivery, breastfeeding difficulties, long-term back pain or long-term urinary incontinence.

4. regional anesthesia

- provides excellent analgesia with minimal depressant effects
- hypotension is the most common complication
- maternal BP monitored q2-5 min for 15-20 min after initiation and regularly thereafter
- epidural usually given as it preferentially blocks sensation, leaving motor function intact

Options for Caesarean Section

1. **regional:** spinal or epidural
2. **general:** used if contraindications or time precludes regional blockade

Potential complications of anesthesia in Caesarean section:

- aspiration under general anesthesia: due to increased gastroesophageal reflux
- hypotension and/or fetal distress: caused by aortocaval compression; corrected by turning patient into the left lateral decubitus (LLD) position or using left uterine displacement (LUD)
- unintentional total spinal anesthesia
- LA-induced seizures: due to intravascular injection of LA
- post-dural puncture headache
- nerve injury (rare)

Pediatric Anesthesia

Respiratory System

- in comparison to adults, anatomical differences in infants include (Figure 11)
 - large head, short trachea/neck, large tongue, adenoids and tonsils
 - narrow nasal passages (obligate nasal breathers until 5 months)
 - narrowest part of airway at the level of the cricoid vs. glottis in adults
 - epiglottis is longer, U shaped and angled at 45 degrees; carina is wider and is at the level of T2 (T4 in adults)
- physiologic differences include
 - faster RR, immature respiratory centres which are depressed by hypoxia/hypercapnea (airway closure occurs in the neonate at the end of expiration)
 - less oxygen reserve during apnea – decreased total lung volume, vital and functional reserve capacity together with higher metabolic needs
 - greater V/Q mismatch – lower lung compliance due to immature alveoli (mature at 8 years)
 - greater work of breathing – greater chest wall compliance, weaker intercostals/diaphragm and higher resistance to airflow
- a pediatric breathing unit is required for all children <20 kg

Cardiovascular System

- blood volume at birth is approximately 80 mL/kg; transfusion should be started if >10% of blood volume lost
- children have a high pulse rate and low BP
- CO is increased by increasing HR, not stroke volume because of low heart wall compliance; therefore, bradycardia → severe compromise in CO

Temperature Regulation

- vulnerable to hypothermia
- minimize heat loss by use of warming blankets, covering the infant's head, humidification of inspired gases and warming of infused solutions

Central Nervous System

- the MAC of halothane is increased compared to the adult (i.e. 0.75% adult, 0.87% neonates, 1.2% infant)
- the neuromuscular junction is immature for the first 4 weeks of life and thus there is an increased sensitivity to non-depolarizing relaxants
- parasympathetics mature at birth, sympathetics mature at 4-6 months → autonomic imbalance
- infant brain is 12% of body weight and receives 34% of CO (adult: 2% body weight and 14% CO)

Glucose Maintenance

- infants less than 1 year can become seriously hypoglycemic during pre-operative fasting and post-operatively if feeding is not recommenced as soon as possible
- after 1 year children are able to maintain normal glucose homeostasis in excess of 8 hours



Nociceptive Pathways in Labour and Delivery

Labour

- Cervical dilation and effacement
- Visceral nerve fibres entering the spinal cord at T10-L1

Delivery

- Distention of lower vagina and perineum
- Somatic nociceptive impulses via the pudendal nerve entering the spinal cord at S2-S4

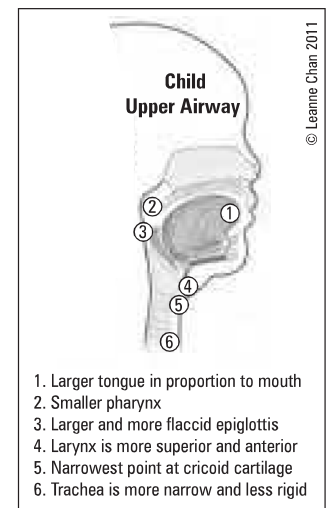


Figure 11. Comparison of Pediatric vs. Adult Airway



To increase alveolar minute ventilation in neonates, increase respiratory rate, not tidal volume.

Neonate 30-40 bpm

1-13 yrs $\frac{24 - \text{[age/2]}}{\text{min}}$



ETT Sizing in Pediatrics

Diameter of tracheal tube in children (mm) after 1 year = $\text{[age/4]} + 4$

Length of tracheal tube (cm) = $\text{[age/2]} + 12$

Pharmacology

- higher dose requirements because of higher TBW (75% vs. 60% in adults) and greater volume of distribution
- barbiturates/opioids more potent due to greater permeability of BBB
- muscle relaxants
 - non-depolarizing
 - ♦ immature NMJ, variable response
 - depolarizing
 - ♦ must pretreat with atropine or may experience profound bradycardia, sinus node arrest due to PNS > SNS (also dries oral secretions)
 - ♦ more susceptible to arrhythmias, hyperkalemia, rhabdomyolysis, myoglobinemia, masseter spasm, and malignant hyperthermia

Uncommon Complications

Malignant Hyperthermia (MH)

- hypermetabolic disorder of skeletal muscle
- due to an uncontrolled increase in intracellular Ca (because of an anomaly of the ryanodine receptor which regulates the Ca channel in the sarcoplasmic reticulum of skeletal muscle)
- autosomal dominant (AD) inheritance
- incidence of 1-5:100,000, may be associated with skeletal muscle abnormalities such as dystrophy or myopathy
- anesthetic drugs triggering MH crises
 - volatile anesthetics: any drug ending in “-ane”
 - depolarizing relaxants: succinylcholine (SCh), decamethonium

Clinical Picture

- onset: immediate or hours after contact with trigger agent
 - increased oxygen consumption
 - increased end-tidal CO₂ on capnograph
 - tachycardia/dysrhythmia
 - tachypnea/cyanosis
 - increased temperature (late sign)
 - hypertension
 - diaphoresis
- muscular symptoms
 - trismus (masseter spasm) common but not specific for MH (occurs in 1% of children given SCh with halothane anesthesia)
 - tender, swollen muscles due to rhabdomyolysis
 - trunk or total body rigidity

Complications

- death
- coma
- disseminated intravascular coagulation (DIC)
- muscle necrosis/weakness
- myoglobinuric renal failure/hepatic dysfunction
- electrolyte abnormalities (e.g. hyperkalemia) and secondary arrhythmias
- ARDS
- pulmonary edema

Prevention

- suspect MH in patients with a family history of problems/death with anesthetic
- dantrolene prophylaxis no longer routine
- avoid all trigger medications (use regional if possible) and use “clean” equipment
- central body temp and end-tidal CO₂ monitoring

Malignant Hyperthermia Management [Based on Malignant Hyperthermia Association of the U.S. (MHAUS) Guidelines, 2008]

1. notify surgeon, discontinue volatile agents and succinylcholine, hyperventilate with 100% oxygen at flows of 10 L/min or more; halt the procedure as soon as possible
2. dantrolene 2.5 mg/kg rapidly IV, through large-bore IV if possible
 - repeat until there is control of signs of MH; sometimes up to 30 mg/kg is necessary
3. bicarbonate 1-2 mEq/kg if blood gas values are not available for metabolic acidosis

**Signs of Malignant Hyperthermia**

- Unexplained rise in end-tidal CO₂
- Increase in minute ventilation
- Tachycardia
- Hyperthermia (late sign)
- Rigidity

**Basic Principles of MH Management**

- CALL FOR HELP
- Turn off potential triggering agents
- Notify operating personnel
- Administer dantrolene 2.5 mg/kg q5minutes
- Cool patient to 38°C
- Monitor and correct blood gases, electrolytes, and glucose

4. cool the patients with core temp $>39^{\circ}\text{C}$
 - lavage open body cavities, stomach, bladder, rectum, apply ice to surface, infuse cold saline IV
 - stop cooling if temp is $<38^{\circ}\text{C}$ and falling to prevent drift to $<36^{\circ}\text{C}$
5. dysrhythmias usually respond to treatment of acidosis and hyperkalemia
 - use standard drug therapy except Ca channel blockers as they may cause hyperkalemia and cardiac arrest in presence of dantrolene
6. hyperkalemia
 - treat with hyperventilation, bicarbonate, glucose/insulin, calcium
 - bicarb 1-2 mEq/kg IV, calcium chloride 10 mg/kg or calcium gluconate 10-50 mg/kg for life-threatening hyperkalemia and check glucose levels hourly
7. follow ETCO_2 , electrolytes, blood gases, CK, core temperature, urine output and colour with Foley catheter, coagulation studies
 - if CK and/or potassium rises more than transiently or urine output falls to less than 0.5 ml/kg/hr, induce diuresis to >1 ml/kg/hr urine to avoid myoglobinuric renal failure
8. maintain anesthesia with benzodiazepines, opioid, and propofol
9. transfer to ICU bed

Common Medications

Table 11. Intravenous Induction Agents

	Propofol (Diprivan®)	Thiopental (Pentothal®, sodium thiopental, sodium thiopentone)	Ketamine (Ketalar®, Ketaject®)	Benzodiazepines [midazolam (Versed®), diazepam (Valium®), lorazepam (Ativan®)]
Class	Alkylphenol – hypnotic	Ultra-short acting thiobarbiturate – hypnotic	Phencyclidine (PCP) derivative – dissociative	Benzodiazepines
Action	- Inhibitory at GABA synapse - Decreased cerebral metabolic rate + blood flow, decreased ICP, decreased SVR, decreased BP, and decreased SV	- Decreased time Cl channels open facilitating GABA and suppressing glutamic acid - Decreased cerebral metabolism + decreased blood flow, decreased CPP, decreased CO, decreased BP, decreased reflex tachycardia, decreased respiration	- May act on NMDA, opiate and other receptors - Increased HR, increased BP, increased SVR, increased coronary flow, increased myocardial O_2 uptake, CNS + respiratory depression, bronchial smooth muscle relaxation	- Causes increased glycine inhibitory neurotransmitter, facilitates GABA - Produces antianxiety and skeletal muscle relaxant effects - Minimal cardiac depression
Indications	- Induction - Maintenance - Total intravenous anesthesia (TIVA)	- Induction - Control of convulsive states	Major trauma, hypovolemia, severe asthma because sympathomimetic	Used for sedation, amnesia and anxiolysis
Caution	- Allergy (egg, soy) - Pts who cannot tolerate sudden decreased BP (i.e. fixed cardiac output or shock)	- Allergy to barbiturates - Uncontrolled hypotension, shock, cardiac failure - Porphyria, liver disease, status asthmaticus, myxedema	- Ketamine allergy - TCA medication (interaction causes HTN and dysrhythmias) - History of psychosis - Pt cannot tolerate HTN (e.g. CHF, increased ICP, aneurysm)	Marked respiratory depression
Dosing	- IV induction: 2.5-3.0 mg/kg (less with opioids or premeds) TIVA - Unconscious <1 min - Lasts 4-6 min $t_{1/2}=0.9$ hrs - Decreased post-op sedation, recovery time, N/V	- IV induction: 3-5 mg/kg TIVA - Unconscious about 30s - Lasts 5 min - Accumulation with repeat dosing – not for maintenance $t_{1/2}=5-12$ hrs - Post-op sedation lasts hours	- IV induction 1-2 mg/kg - Dissociation in 15s, analgesia, amnesia and unconsciousness in 45-60s - Unconscious for 10-15 min, analgesia for 40 min, amnesia for 1-2 hrs $t_{1/2} \approx 3$ hrs	- Onset less than 5 minutes if given IV - Duration of action long but variable/somewhat unpredictable
Special Considerations	0-30% decreased BP due to vasodilation - Reduce burning at IV site by mixing with lidocaine	Combining with rocuronium causes precipitates to form	- High incidence of emergence reactions (vivid dreaming, out-of-body sensation, illusions) - Pretreat with glycopyrrolate to decrease salivation	- Antagonist: flumazenil (Anexate®) competitive inhibitor, 0.2 mg IV over 15s, repeat with 0.1 mg/min (max of 2 mg), $t_{1/2}$ of 60 minutes - Midazolam also has amnestic (antegrade) effect + decreased risk of thrombophlebitis

Table 12. Opioids

Agent	Infusion Rate	PCA Dose	PCA Lockout Interval
Morphine	0.3-0.9 mg/h	0.2-0.3 mg	30 minutes
Fentanyl	25-50 µg/h	20-30 µg	15 minutes
Hydromorphone	0.1-0.2 mg/h	0.15 µg	30 minutes

Agent	Moderate Dose (IV)	Onset	Duration	Special Considerations
Morphine	0.2-0.3 mg/kg	Moderate (5-10 min)	Moderate (4-5 h)	Histamine release leading to decrease in BP
Meperidine (Demerol®)	2-3 mg/kg	Moderate (10 min)	Moderate (2-4 h)	Anticholinergic, hallucinations, less pupillary constriction than morphine, metabolite build up may cause seizures
Codeine	0.5-1 mg/kg (no IV)	Late (30-60 min)	Moderate (4-6 h)	Primarily post-operative use, not for IV use
Hydromorphone (Dilaudid®)	30-80 µg/kg	Moderate (15 min)	Moderate (4-5 h)	
Fentanyl	3-10 µg/kg	Rapid (<5 min)	Short (0.5-1 h)	Transient muscle rigidity in very high doses
Remifentanyl	0.5-1.5 µg/kg	Rapid (1-3 min)	Ultra short (<10 min)	Only use during induction and maintenance of anesthesia

In general, parenteral route is 2-3 times more potent than oral.

Table 13. Volatile Inhalational Agents

	Sevoflurane	Desflurane	Isoflurane	Enflurane	Halothane	Nitrous oxide (N ₂ O)*
MAC	2.0	6.0	1.2	1.7	0.8	104 (% gas in O ₂)
CNS	Increased ICP	Increased ICP	Decreased cerebral metabolic rate Increased ICP	ECG seizure-like activity, increased ICP	Increased ICP and CBF	—
Resp	Respiratory depression (severely decreased TV, increased RR), decreased response to respiratory CO ₂ reflexes, bronchodilation					—
CVS	Less decrease of contractility, stable HR	Tachycardia with rapid increase in concentration	Decreased BP and CO, increased HR, theoretical chance of coronary steal**	Stable HR, decreased contractility	Decreased BP, CO, HR and conduction Sensitizes myocardium to epinephrine-induced arrhythmias	Can cause decreased HR in pediatric cases in those with existing heart disease
MSK	Muscle relaxation, potentiation of other muscle relaxants, uterine relaxation					

*Properties and Adverse Effects of N₂O

Due to its high MAC, nitrous oxide is combined with other anesthetic gases to attain surgical anesthesia. A MAC of 104% is possible in a pressurized chamber only. Second Gas Effect: see Determinants of Speed of Onset of Volatile Anesthetics sidebar, A6.

Expansion of closed spaces: closed spaces such as a pneumothorax, the middle ear, bowel lumen and ETT cuff will markedly enlarge if N₂O is administered.

Diffusion hypoxia: During anesthesia, the washout of N₂O from body stores into alveoli can dilute the alveolar [O₂], creating a hypoxic mixture if the original [O₂] is low.

**Coronary Steal: N₂O causes small vessel dilation which may compromise blood flow to poorly perfused areas of heart.

Table 14. Depolarizing Muscle Relaxants (Non-Competitive): Succinylcholine (SCh)

Mechanism of Action	Mimics ACh and binds to ACh receptors causing prolonged depolarization; initial fasciculation may be seen, followed by temporary paralysis secondary to blocked ACh receptors by SCh
Intubating Dose	1-2 mg/kg
Onset	30-60 seconds – RAPID (fastest of all muscle relaxants)
Duration	5-10 minutes – SHORT (no reversing agent for SCh)
Metabolism	SCh is hydrolyzed by plasma cholinesterase (pseudocholinesterase), found only in plasma and not at the NMJ
Indications	- Assist intubation - Increased risk of aspiration (need rapid paralysis and airway control) - Short procedures (e.g. full stomach), DM, hiatus hernia, obesity, pregnancy, trauma - Electroconvulsive therapy (ECT) - Laryngospasm
Side Effects	SCh also stimulates muscarinic cholinergic autonomic receptors (in addition to nicotinic receptors) - May cause bradycardia, dysrhythmias, sinus arrest, increased secretions of salivary glands (especially in children) Hyperkalemia - Disruption of motor nerve activity causes proliferation of extrajunctional (outside NMJ) cholinergic receptors - Depolarization of an increased number of receptors by SCh may lead to massive release of potassium out of muscle cells - Patients at risk: 3rd degree burns 24 hrs-6 mths after injury - Traumatic paralysis or neuromuscular diseases (e.g. muscular dystrophy) - Severe intra-abdominal infections - Severe closed head injury - Upper motor neuron lesions - Can trigger malignant hyperthermia (MH) - Increase ICP/intraocular pressure (IOP)/intra gastric pressure (no increased risk of aspiration if competent lower esophageal sphincter) Fasciculations, post-op myalgia – may be minimized if small dose of non-depolarizing agent given before SCh administration
Contraindications	
Absolute	Known hypersensitivity or allergy, positive history of malignant hyperthermia, myotonia (m. congenita, m. dystrophica, paramyotonia congenital), high risk for hyperkalemic response
Relative	Known history of plasma cholinesterase deficiency, myasthenia gravis, myasthenic syndrome, familial periodic paralysis, open eye injury

Table 15. Non-Depolarizing Muscle Relaxants (Competitive)

Mechanism of Action	Competitive blockade of postsynaptic ACh receptors preventing depolarization					
Classification	Short	Intermediate			Long	
	Mivacurium	Rocuronium	Vecuronium	Cisatracurium	Pancuronium	Doxacurium
Intubating Dose (mg/kg)	0.2	0.6	0.1	0.1	0.1	0.05
Onset (min)	2-3	1.5	2-3	3	3-5	5-7
Duration (min)	15-25	30-45	45-60	40-60	90-120	90-120
Metabolism	Plasma cholinesterase	Liver (major) Renal (minor)	Liver	Hofmann Eliminations	Renal (major) Liver (minor)	Renal
Indications	Assist intubation, assist mechanical ventilation in some ICU patients, reduce fasciculations and post-op myalgias secondary to SCh					
Side Effects						
Histamine Release	Yes	No	No	No	No	Yes
Other	—	—	—	—	Tachycardia	—
Considerations	Increased duration of action in renal or liver failure	Quick onset of rocuronium allows its use in rapid sequence induction Cisatracurium is good for patients with renal or hepatic insufficiency			Pancuronium if increased HR and BP desired, doxacurium if cardiovascular stability needed	

Table 16. Reversal Agents for Non-Depolarizing Relaxants

Cholinesterase Inhibitor	Neostigmine	Pyridostigmine	Edrophonium
Onset and Duration	Intermediate	Longest	Shortest
Mechanism of Action	Inhibits enzymatic degradation of ACh, increases ACh at nicotinic and muscarinic receptors, displaces non-depolarizing muscle relaxants Muscarinic effects of reversing agents include unwanted bradycardia, salivation and increased bowel peristalsis*		
Dose	0.04-0.08 mg/kg	0.1-0.4 mg/kg	0.5-1 mg/kg
Recommended Anticholinergic	Glycopyrrolate	Glycopyrrolate	Atropine
Dose of Anticholinergic per mg	0.2 mg	0.05 mg	0.014 mg

*Atropine and glycopyrrolate are anticholinergic agents administered during the administration of reversal agents to minimize muscarinic effects

Table 17. Local Anesthetic Agents

	Max. Dose	Max. Dose with Epinephrine	Potency	Duration
chloroprocaine	11 mg/kg	14 mg/kg	Low	15-30 min
lidocaine	5 mg/kg	7 mg/kg	Medium	1-2 hours
bupivacaine	2.5 mg/kg	3 mg/kg	High	3-8 hours

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